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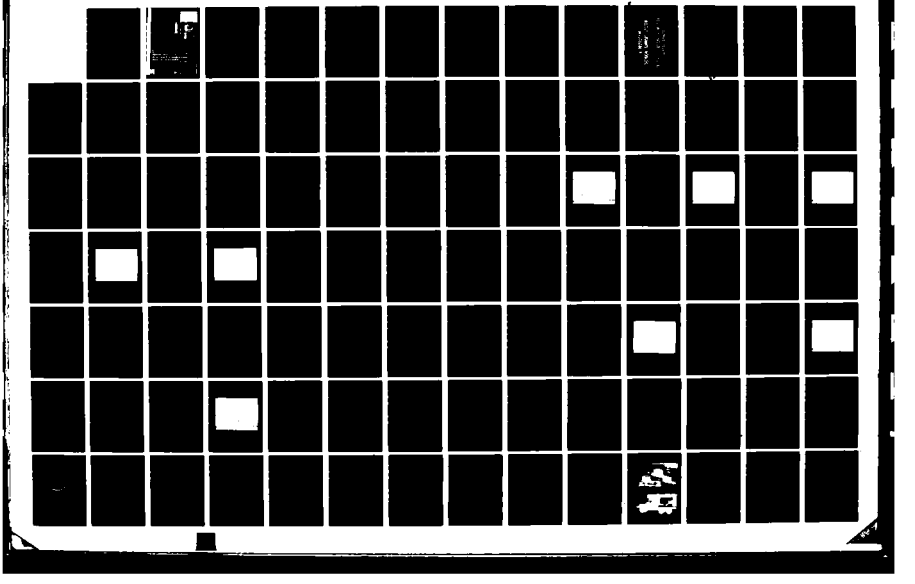

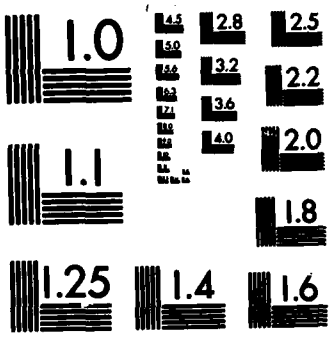

Georgia Institute of Technology

A

PROTOTYPE DECISION SUPPORT SYSTEM

THE LOCATION OF MILITARY WATER POINTS

by

Monty Joseph Anderson, CPT EN

June, 1980

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"Original contains color plates: All DTIC reproductions will be in black and white"

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PROTOTYPE DECISION SUPPORT SYSTEM

FOR

THE LOCATION OF MILITARY WATER POINTS

A THESIS

Presented to

The Faculty of the Division of Graduate Studies

by

Monty Joseph Anderson

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Operations Research

Georgia Institute of Technology

June, 1980

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SUMMARY

A demonstration prototype Decision Support System (DSS) has been developed, documented, and validated for interactive selection of water supply point locations by the U.S. Army Division Engineer.

The DSS aids the user in digitizing, from a map, a network having nodes at each possible supply point, each possible customer (combat unit) location, and each relevant crossroads, with distances automatically entered as roads are traced. It also assists in providing and revising problem-specific data on demands, supplies, and customer locations. It aids in performing an interactive optimization procedure based on the location-allocation optimization model to identify efficient solutions, in investigating the consequences of uncertainties or changes in data, and in the integration of considerations not reflected in the location-allocation formulation, e.g., factors not practically quantifiable such as mission, enemy, terrain and command guidance.

The prototype operates in stand-alone mode (no host computer) on the experimental DSS vehicle currently being used in DSS research by the U.S. Army Computer Systems Command: A Chromatics CG-1999 color graphics system with light pen, digitizer, 64K memory, and dual or single floppy disk drive. The prototype is ready for initial user testing.

Although the input and output of the prototype are specific to water point location analysis, the system also constitutes a prototype for interactive solution of location-allocation problems in general.

A PROTOTYPE DECISION SUPPORT SYSTEM

FOR THE LOCATION OF MILITARY WATER POINTS

CHAPTER I

INTRODUCTION

The usual availability of pure water in a peacetime environment is often disrupted during combat. Battles may be fought in deserts or in areas whose water resources have been contaminated or made unavailable. In developed areas a high probability exists that the civil administration and supporting services will be severely disrupted by combat. Historically, water, waste disposal, and sewage systems have been seriously degraded by combat activities. Should chemical and/or biological weapons be employed, providing potable water would be of even greater concern. Definite procedures have been published to guide U.S. Army Division Engineers in providing fresh water to units under Division control.[18] See Appendix VII.

The purpose of this research is to provide a prototype of a Decision Support System (DSS) for the Division Engineer. It will assist him in selecting, from among the potential water resupply sites, those sources that minimize total resupply travel distance consistent with conditions and requirements.

This Decision Support System, subsequently referred to as DSS, is not intended as the ultimate tool for locating logistical facilities on routes of communication. It does permit the lower level manager to make use of existing operations research techniques in the solution of everyday problems. No prior knowledge of operations

research is required. By permitting and encouraging human interaction in the selection process, all of the previous knowledge and experience of the logistician can be supplemented.

Criteria for Water Point Site Selection

It is necessary to keep in mind that this DSS is not intended to make the actual selection of the best logistical facility locations, henceforth referred to as water points. This is too complex a problem to build a mathematical model of without requiring the input of excessive amounts of data. Presently, only the human mind is capable of assimilating all of the criteria considered in selecting locations.

The criteria considered by the logistics officer[18] in making his decisions are many. If the current tactical situation calls for defensive operations, then the defense and survivability of the water points may be of paramount importance. This is particularly true if there is insurgent activity behind the FEBA(Forward Edge of the Battle Area). An offensive scenario may call for the supported units involved in the attack to receive priority so as to reduce their required resupply effort compared to other units. The threat of nuclear warfare may make dispersion the most important criterion for choosing locations. See also Appendix VII. The fluid nature of modern warfare does not permit the input of large amounts of supporting data.

This DSS is a prototype to demonstrate how operations research

techniques can be implemented on advanced computer graphics equipment. As implemented, this DSS aids the user in selecting sites while minimizing the resupply effort required. All other considerations are taken into account by the human intervention into the selection process. Throughout the remainder of this thesis, these selection criteria will be referred to by the key words: mission, enemy, terrain and command guidance.

Historical and Military Perspective

Logistical decision makers in the military are inundated with factors, criteria, checklists and immediate command guidance when selecting resupply point locations. In spite of the large amount of work done to define what is important in the siting of logistical facilities, the decision maker currently has few resources other than his mental capabilities with which to make his selection or evaluate subjectively the various alternatives.

The increased lethality and resulting destructiveness of warfare has placed greater demands than ever before on the supply system. As one of the consequences it is desirable to make the resupply effort as efficient as possible while providing essential support to the tactical commander. One readily available area for improving efficiency is in shortening the distance traveled by both the supported units to get needed materials and by the combat service support elements in maintaining their stockages. By locating these resupply facilities in such a manner as to minimize necessary travel, both the time delay response to demands and the strain on resupply equipment are reduced.

In an Army division, a force of over 15,000 personnel, the Division Engineer is responsible for providing potable water. This responsibility consists of identifying the potential sites and developing the sites as necessary in order to insure access.[18] Access is required for both the engineer operated water purification equipment teams and the supported units who transport their respective water requirements.

The transport of potable water is normally accomplished by the supported units utilizing trucks to pull the standard 400 gallon capacity water trailer.[49] The number of these trailers available to the unit varies depending upon its authorized personnel strength. This number is not a significant factor in this study since only one trailer at a time may be towed by a 2½-ton truck or its equivalent. This necessitates one round trip distance being traveled by the unit for each 400 gallon trailer of water consumed. A round trip is defined to be the distance traveled from the current location of the unit to a water point and back by the shortest route.

The water purification equipment authorized for the engineer units who operate them is the 1500 gallon-per-hour truck-mounted unit with 7,500 gallons of on-site storage capacity.[49] The water purification equipment sets have no water delivery capability. Each division has five of these equipment sets. This authorized number is fixed although the actual number available may be affected by mission, enemy, terrain, and respective equipment sets' operational readiness. See Appendix III.

Water Point Site Selection

Water sources are described in [18]:

a. A satisfactory water source is one of sufficient quantity to meet troop needs and of such quality that it can be approved for use or readily purified by available equipment. A water source developed for military use is called a water point.
b. Water sources are classified as follows:
(1) Surface water: streams, lakes, and rivers.
(2) Ground water: wells and springs.
(3) Sea water.
(4) Rain, snow and ice.(quote from [18])

The Division Logistics Officer[18] is responsible for providing the necessary water requirement information. With this the Division Engineer performs map reconnaissance and concurrently reviews intelligence summaries in selecting potential water point sites. On the maps are shown the road nets that provide the primary data for this research, which is distance. Hopefully, the number of potential sites exceeds the actual number that are required. The Division Engineer makes estimates as to the suitability of these sites and dispatches reconnaissance teams.

These teams then make a detailed inspection of the preliminary sites and prepare a report, DA Form 1711-R and DA Form 1712-R, on each site visited. See Appendix II. The factors to be considered are: (i) quantity of water, (ii) quality of water, (iii) routes of communication or access and eggress, and (iv) site conditions.[18] See Appendix VII.

It should be noted that the results of this research could be applied both before and after the ground reconnaissance. A before application based on estimates would insure that only the most pre-

ferred sites were visited by the reconnaissance team. Subsequently, this same data base of distances from the map would be used to make the final selection. The reconnaissance reports would provide the actual site capacities and equipment limitations, if any, to use in the evaluation.

The present state of the art requires that a subjective evaluation be made by the Division Engineer as to which sites are to be designated and manned for water points.[18] He must rely upon his professional judgement alone, without the benefit of numerous location analysis techniques presently available to the operations research analyst. Since it is not practical to educate all division engineers as analysts, nor to provide them with large computers, nor to let their decisions be based on quantifiable data alone, the goal is to provide a prototype DSS ready for user testing. This would allow the engineer to interact with the computer in terms of data that he can relate to while the DSS acts as a translator into and back out of the world of the analyst.

Assumptions

In order to construct a mathematical model of this problem a number of assumptions were necessary. They are intended to place the user in the correct frame of reference to obtain maximum usefulness from this prototype system. The four assumptions that had the most impact on the final design are given here with their justification. The remaining assumptions, intended primarily for clarification, are summarized in Appendix A.

(1) The resupply effort and/or cost is proportional to the total distance all customers travel in units of gallon-miles.

It is readily accepted that many other measures of resupply effort exist. Vehicle size, fuel consumption, manhour cost for the operator, intangible costs due to the nonavailability of the vehicle for other uses and capacity per trip are a few of these. A cursory examination leads one to suspect that these measures are highly correlated with total distance traveled. Not only should the dependent variable selected accurately reflect "real world" costs, it should be reasonably amenable to quantification. Gallon-miles appears to satisfy both of these criteria.

(2) All locations and supply/demand data are considered to be static, i.e., fractions of a day are not considered.

The anticipated frequency with which water points are moved was the primary consideration for choosing a static as opposed to a dynamic approach. Movement of supported units is dictated by the tactical situation and may be more or less frequent than daily. The movement of water point equipment sets may not be necessarily so costly as to justify moving them in advance of the supported units. The daily frame of reference facilitates the utilization of existing publications for estimating supply/demand, e.g., demand data is in terms of gallons per man per day.[18]

(3) All needed information or data required is readily available to the Division Engineer.

The information required for this prototype DSS consists of any map drawn to scale, present supported unit locations with respective personnel strengths, water point reconnaissance reports, and current operations orders. The map provides the road network that is traced in on the digitizer pad. Supported unit locations are used to specify the demand points, and the strengths are required to estimate the amount of respective demand. The preferred water point locations and site capacities may be identified from the reconnaissance reports. See Appendix II. The Operations Order provides all of those site location considerations not included in this prototype, i.e., security requirements, planned offensive/defensive operations, anticipated enemy actions, etc.

(4) There is no additional fixed cost of establishing one water point site over another.

This simplifying assumption is possible due to the human interaction in the solution process. This decision, to base the cost of locating the water points solely as a function of distance from the units it supplies, was not arrived at easily. It was necessary to keep the cost criteria simple to facilitate implementation on equipment that could conceivably be placed in the division's combat engineer battalion. It should be noted that the Division Engineer is both the commander of the division's engineer battalion and a special staff officer.

There is no civilian parallel to the military situation which can be adapted to determine costs. A few of the tactical criteria are

site drainage, security, bivouac for operating personnel and future tactical operations. See Appendix VII. For the military there are no overtime costs. One site may require more preparation than another, but this is best taken into account by the user once he has assessed the desirability of locating a water point at a particular location. The truck that pulls the water trailer is a general-purpose truck not solely devoted to water resupply. It is also used to transport other types of supplies that are usually not located with or near the water point. The requirement then becomes one of minimizing the non-available time of the truck. The cost factor is then merely the distance the trucks must travel for water. The human is more capable than any mathematical model of taking into account the myriad of tactical and operational factors associated with site selection.

Analysis of the Water Point Location Problem

The problem that this research addresses is in the category known as location-allocation. Problems of this nature involve the placement of one or more sources which will be used to satisfy, in an optimum manner, demands at various destinations. What must be determined is the location of the sources and the distribution or allocation of the commodity so that the destinations are supplied most economically.

The supply points are selected from a finite set that includes all acceptable locations. This problem is most easily visualized and subsequently solved as that of selecting source nodes in a distribution network.

The establishment of a source involves setting up a distribution center for the production of goods or in this case, gallons of water. The allocation part involves the distribution of the goods from these sources, through intermediate points such as road intersections, to the demand points. When either the source site selection or allocation of the distribution of goods is considered separately the solution is greatly simplified. However, in order to correctly analyze the complete problem, both aspects must be considered at once. The location of the supply points must be made simultaneously with the determination of the most economical goods allocation.

This problem can then be stated as the following:

Given:

The supported unit locations, $\{x_j, y_j\}$ and demands, $\{b_j\}$.

The water point locations, $\{x_i, y_i\}$ and capacities, $\{q_i\}$.

Round trip distances among all points, $\{d_{ij}\}$.

The total number of water point equipment sets available, $\{r\}$.

Select:

The number, $\{y_i\}$ and location, $\{x_i, y_i\}$ of the water points.

The needed production capacity of each source, $\{q_i\}$.

The allocation of the water from each water point to each supported unit.

Methodology

A thorough study of the potential users' requirements, implementation equipment limitations and existing solution procedures resulted in a heuristic approach being selected. This approach will give a good, but not necessarily optimal, answer. The solution method implemented is:

(1) Data input by user and machine: Network $\{I,J\}$, distances $\{d_{ij}\}$ and potential combat unit and water point locations.

(2) Specification by user of supported unit demands: $\{b_j\}$

(3) Selection by user of the number of open sources $\{y_i\}$ and their respective supplies $\{q_i\}$.

(4) Shortest path solution by machine: Cost $\{c_{ij}\}$
(Only on initial iteration or upon changing water point locations.)

(5) Transportation solution by machine: Flows $\{x_{ij}\}$ and total cost Z.

(6) Presentation by machine of solution quality indicators: Loading of each source $\Sigma_i x_{ij}$ vs q_i, allocation of costs per unit of flow over water points $\Sigma_j x_{ij}c_{ij}/\Sigma_i x_{ij}$, total distances traveled by demand points $\Sigma_j x_{ij}c_{ij}$ and alternative costs for each demand point.

(7) Decision by user: Return to either (1), (2), (3) or stop.

The first step is the preparation of an initial data base. The road network in the area of concern is identified and input using the digitizer pad. All potential, but not necessarily utilized, supported unit locations and water point locations are entered as nodes on the network.

The second step is specification by the user of the estimated demand for each supported unit. For each unit a personnel strength is

entered. A demand is computed and then transformed to an integer number of trips that the supported unit will have to make in satisfying its demand per day. This integer value is obtained by rounding up.

The third step is the selection by the user of those water point locations that are to be considered and their respective supply limitations. The minimum of either the amount of water available or capacity of the equipment to purify water is determined and used as that site's supply capacity.

The fourth step is the computation of all shortest paths from each of the selected water points to all other points in the network.

The fifth step is the allocation of water supply capacity to units' requirements so that total distance traveled is minimized.

The sixth step is a sensitivity analysis of the results presented to the user in graphical format. This enables the user to readily identify which of his potential water points are not fully utilized and are therefore, candidates for elimination. Any of the supporting numerical data can be requested and displayed concurrently with the graphs. "What if" questions may be proposed and analyzed by forcing a particular supported unit to be serviced by a particular water point. This great flexibility for rapid analysis and cross checking allows the user to take into account all of those factors that cannot be accurately or practically modeled, i.e., mission, enemy, terrain and command guidance.

The seventh step involves the user making a decision as to

which sites are to be opened or closed. The user may then return to any of the first three steps and initiate a more thorough analysis. This subsequent analysis can then also be a candidate solution and modified as desired.

One limitation of this procedure is that an exact optimum is probably not attained, e.g., we start with all sites used and eliminate as many as the users' judgement dictates. Since experience with optimization dictates that even an exact optimum may not be acceptable to the user without some modification, this will not detract from its usefulness. Another limitation is that a human must identify the possible sites to be closed from graphs. This opportunity for error will be present in the final answer even though pattern recognition is one of the functions a human performs best and the computer worst.

Overview

The introduction is intended to familiarize the reader with the basic design considerations and operations research techniques employed. Chapter II will cover what similar research has been conducted in this area. A description of the mathematics involved will also be found. Here both the location-allocation formulation and the reduced transportation formulation is presented. Chapter III provides a step-by-step example approach of the decision making procedure with relevant pictures from the screen.

Implementation of the four step solution procedure can be reviewed in Chapter IV, including a flowchart outline. In Chapter V

the results and performance of the program on a case problem are documented. See Appendix VI. This final chapter also suggests further development of this prototype DSS.

The code for programs NTRACE and COMPUTE may be found in Appendix IV and V respectively.

CHAPTER II

MATHEMATICAL FORMULATION AND PAST WORK

Mathematical Formulation

The mathematical formulation that comes closest to representing the Water Point Location problem is the location-allocation problem. As given by Ellwein,[16] the formulation is:

$$\text{minimize } Z = \sum_{i}^{m}\sum_{j}^{n} d_{ij}x_{ij} + \sum_{i}^{m} g_i \left(\sum_{j} x_{ij}\right) + \sum_{i}^{m} f_i y_i$$

subject to:

$$\sum_{i}^{m} x_{ij} \geq b_j \qquad j=1,2,\cdots,n \qquad \text{"demand at supported unit j"}$$

$$\sum_{j}^{n} x_{ij} \leq q_i y_i \qquad i=1,2,\cdots,m \qquad \text{"supply at water point i"}$$

$$\sum_{i\in S_t}^{m} y_i \leq r_t \qquad t=1,2,\cdots,p \qquad \text{"max. \# of water points r"}$$

$$x_{ij} \geq 0 \qquad \text{"all supply is positive"}$$

$$y_i = 0 \text{ or } 1 \qquad \text{"no fractional water points"}$$

The zero-one decision variables y_i indicate whether water point i is selected for use; y_i=0 implies that location i is not used and y_i=1 implies that it is used. Each continuous decision variable x_{ij} represents the non-negative amount of water that point i provides

to supported unit j. The first two constraints state that the demand at each supported unit must be satisfied and that the availability of water at a point must not be exceeded, respectively. It can be seen that the output from point i, $\Sigma_j x_{ij}$, can be positive only if a source is established there, i.e., only if $y_i=1$. The third inequality represents a set of p system configuration constraints where S_t is a subset of the m water point locations and $r_t \leq m$. This is the same as saying that we can not establish more water points than we have water purification equipment sets available.

The objective function is to minimize a function representing both the source and distribution variable costs plus the fixed cost components. All cost coefficients or distances traveled must be greater than zero. The problem then is that of determining the optimal trade-off between a large number of water points with low total distance and a small number of water points with high total distance traveled. This problem formulation is more general than that implemented in this thesis.

The fixed cost represented by f_i for each site will be assumed to be the same for all sites; furthermore, the user chooses the number of water points so that fixed costs may be assumed to be zero. This results in the objective function being expressed as:

$$\text{minimize } Z = \sum_{i}^{m} \sum_{j}^{n} d_{ij} * x_{ij}$$

where x_{ij} is the integer number of trips needed to satisfy the demand for a supported unit at j traveling over the shortest route, d_{ij}, to

water point i.

The third constraint can be deleted since the user specifies those sites to be considered as locations for water points. Subsequent to the analysis he then manually reduces this set again for reevaluation of the entire problem. The demand for the supported units in terms of gallons per man per day may be changed to an integer number of trips required. This is accomplished by dividing by the per trip capacity of the transport or in this case a 400 gallon trailer pulled by a single truck. The resulting answer is rounded up to the nearest integer since realistically the trailer would always be filled on each trip, i.e., one would not pull a 400 gallon trailer and only put 50 gallons in it even if only 50 gallons were required. The capacity of each water point site to provide water can likewise be converted to an integer number of trips available, except that the result is rounded down to insure that supply is not exceeded.

With this, the formulation of P becomes:

$$\text{minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n+1} d_{ij} * x_{ij}$$

subject to:

$$\sum_{j=1}^{n+1} x_{ij} = \left\lceil \frac{q_i}{400} \right\rceil \qquad i=1,2,\cdots,m \qquad \text{"demand is satisfied"}$$

$$\sum_{i=1}^{m} x_{ij} = \left\lfloor \frac{b_j}{400} \right\rfloor \qquad j=1,2,\cdots,n \qquad \text{"supply is not exceeded"}$$

$$x_{ij} \geq 0 \text{ and integer}$$

A dummy demand point is created at location n+1 to absorb all excess supply. This is a necessary condition for the transportation algorithm. The cost of providing supply to the dummy demand point from any source is then zero. In the display of the results the amount of water provided to the dummy demand point is subtracted from the amount produced.

Past Work

A review of published articles has revealed an abundance of reported research on facility location-allocation with capacity constraints.[16,22,23,24,25,27,46] One of the first exact algorithms to deal with the uncapacitated case is that of Efroymson and Ray[14] and Spielberg.[48] Recent research, which includes exact algorithms and computational experience specifically for the capacitated plant problem, has been done by Rardin[44,45,46] and Geoffrion.[23,24,25] An excellent survey of the current state of the art for exact solutions is presented by McGinnis:[38]

> Spielberg was able to solve randomly generated uncapacitated problems with 20 to 100 sites in 1 to 75 minutes on an IBM 360/40[47] and 52-100 sites in 2 to 167 minutes on an IBM 360/50.[48] Rardin[46] solved some randomly generated problems on a Univac 1108 with results summarized in table 3. . . Geoffrion and Graves[24] considered an even more general problem which had two stages of delivery, no customer serviced by more than one supply point, and deliveries to customer identified by point of orgin. The solution procedure they describe is a variant of Benders partitioning algorithm, and was capable of solving problems with up to 30 sites in 17 to 191 seconds on an IBM 360/91. (quote from [38])

All of these presently accepted methods of obtaining global

optimal answers to the location-allocation class of problems with capacity constraints utilize heavily the techniques of integer programming. The codes developed for their implementation require large, high speed computers to produce satisfactory results. Many advances in the rapid solution of these problems have been accomplished by Rardin[45,46] and Geoffrion.[25]

A heuristic procedure by Kuehn and Hamburger[36] represents the first work on solving the plant location problem. Subsequent work by Manne[37] and Feldman, Lehrer, and Ray[17] resulted in approximate algorithms. A major reason for the development of these heuristics was the reduction of computer time necessary to find reasonable solutions. Trade-offs arise in this procedure because of the lack of a guarantee of reaching an optimal solution due to the heuristics, and because of the approximations that are made to the cost equations. The heuristics are used to assign customers to sources and to open or close sources, such that the number of alterratives evaluated is quite small. The result of applying these heuristics is that one can quickly determine a good set of sources in minimum computer time.

> Atkins and Shiver[2] indicate potential savings of from 5 to 15% over good manual solutions when using these techniques. There are simply too many combinations and too much detail to rely on manual techniques for solving this problem. The current state of the art provides a very acceptable alternative. (quote from [35])

The identified difficulty of optimally solving a realistic resupply point location problem and having its solution readily available to the Division Engineer resulted in a heuristic procedure being selected for implementation. (See Chapter I, Methodology) This

is justified by the simultaneously complex and repetitive nature of this problem when placed in the tactical operational environment. The search for an efficient and effective heuristic procedure with the flexibility to handle nearly any situation involved the field of interactive graphics. With the rapid advances in computer technology and its subsequent implementation, interactive graphics solution of location problems has flourished.[6,7,33]

This is primarily due to the mathematical difficulties encountered in obtaining exact answers, i.e., most location problems are considered to be NP-complete which is a class of problems not solvable in all cases. For those that are solvable the effort required to enumerate all of the possible solutions may require large consumption of computer processing time. Interactive graphics allows the human to inject his pattern recognition abilities into the solution process. He thereby eliminates many of the possible, but not optimal solutions from the set of those to be enumerated by the computer.

A desire to implement the heuristic procedure on the state of the art Chromatics color graphics terminal without use of a host computer resulted in a search for efficient algorithms. The use of minicomputers in this area has been facilitated by the work of Glover and Klingman.[26,27,28] They have had significant success at developing highly efficient computer codes for many of the existing algorithms. The desirability of utilizing the Chromatics in this manner is clearly expressed by Elam:

> The availability of efficient mathematical programming software on minicomputer systems could greatly increase the use of

> operations research techniques in industry and government simply by placing a decision-making capability at the finger tips of managers. In fact, since minicomputers are relatively inexpensive, it is also possible to dedicate a minicomputer to solving a specific decision problem and thus create an environment which is conductive to an efficient man/machine decision making system. This could be accomplished by designing the operating system of the minicomputer to improve the human engineering aspects of problem solving that is, to minimize the difficulties of entering, modifying and verifying problem data, passing the problem data to the solution procedure, interpreting the output, and so forth. (quote from [15])

Additional research on this problem has recently been accomplished by Glover[28] and Hudson and Flake.[33]

Three solution procedures for solving the water point location-allocation problem were considered, primal network flow, the out-of-kilter algorithm and the all integer transportation algorithm. The first two have the advantage of being one step procedures that could be applied directly to the problem. Their primary disadvantage is the need to re-solve the entire problem whenever changes are made to the supply or demands.

The choice of the transportation algorithm required that a two step procedure be used. First, an all possible shortest route problem is solved for each water point in the initial candidate set. The shortest distance values are then used to form a cost matrix to be used by the transportation algorithm. This method has the advantages that: (1) The interactive solution approach could be implemented so that one shortest-route problem is solved. This is followed by a sequence of transportation problems all using the existing shortest route values. (2) A large number of "what if" or sensitivity analysis questions can be treated by re-solving the transportation code without

re-solving the shortest-route problem. (3) The best of the existing heuristic procedures for choosing site locations could be added by utilizing the output of the transportation algorithm.

These approaches are generally accepted to be variations on those strategies published by Keuhn and Hamburger,[36] Feldman, Lehrer and Ray,[17] and Maranzana.[31] Khumawala and Whybark[35] have an excellent summary of the first two.

CHAPTER III

THE DECISION MAKING PROCEDURE

The existing decision making process for water point location can be summarized as follows:

Phase 1 - Establish a requirement for water points:

- Step 1 - Collect supported unit data.
- Step 2 - Calculate demand quantities.

Phase 2 - Perform water point site selection:

- Step 1 - Perform a map reconnaissance.
- Step 2 - Dispatch reconnaissance teams to potential sites.
- Step 3 - Make a subjective evaluation of results.
- Step 4 - Select the actual sites.

Phase 3 - Establish water points and inform supported units. [18]

This DSS would modify this as follows:

Phase 1 - Establish a requirement for water points:

- Step 1 - Collect supported unit data.

Phase 2 - Perform water point site selection:

- Step 1 - Perform a map reconnaissance.
- Step 2 - Input road network with digitizer. (In future implementation, obtain a disk with predigitized map.)
- Step 3 - Input unit locations and feasible sites with light pen. (Alternative means of entering data could be provided.)
- Step 4 - DSS computes supply and demand.
- Step 5 - Interactively evaluate feasible water point sites.
- Step 6 - Dispatch reconnaissance teams to potential locations.
- Step 7 - Interactively select actual sites.

Phase 3 - Establish water points and inform supported units.

Phase 4 - Reoptimize original data when the tactical situation changes.

In this interactive DSS there is no exact or abrupt end of the selection process. Analysis of the graphical results can be repeated or revised as desired, using the DSS as a vehicle for storing, viewing, editing and analyzing site locations, entering judgements and opinions, and presenting the solution with supporting data.

There are several avenues for arriving at a decision using the DSS. Features included in the DSS are color computer graphics, giving the user a pictorial view of the map area of interest; techniques for changing the capacities of the potential water points and demands for the respective supported units; use of network analysis to select routes; siting analysis to compare the potential locations; and graphing routines to evaluate the results. The attempt is to provide a flexible system that will fulfill the needs of both novice and experienced users.

The structure is this: The user chooses the water points; with this choice the problem is reduced to a network flow problem. This is solved as a combination of several shortest-path problems and a transportation problem since all the shortest-path problems can be solved in advance. The result is a solution that is optimal for the additional constraint of the water point locations chosen. Pricing information is then given to the user, who can then alter the additional constraints, i.e., change the chosen set of water points; the process is repeated until the user is satisfied.

Possible paths through the subsystems of the DSS may be

depicted as follows:

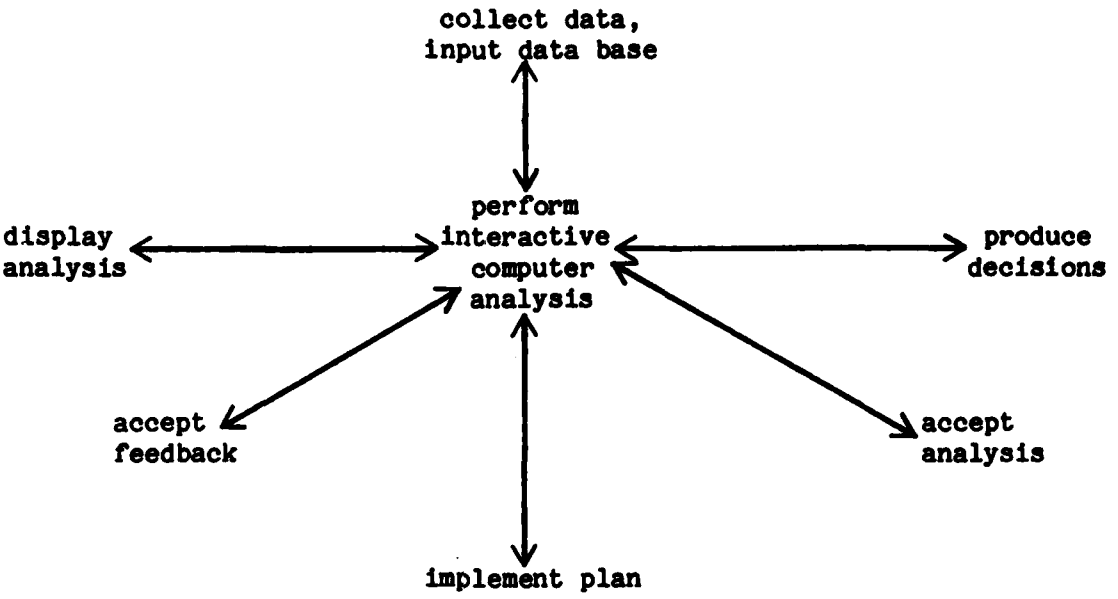


Figure 1. Users' Interaction With the DSS

After calculations have been performed for a given set of open water points, the DSS provides three methods of investigating the sites under consideration: (i) graphical representation of the distances supported units must travel per unit flow and the actual production flow of each water point, (ii) numerical data to investigate the graphical representation, and (iii) sensitivity analysis by forcing a supported unit to be served by a particular water point and re-solving the transportation problem.

There are four different graphs that can be requested. All are accessed by selecting the DISPLAY ANALYSIS menu item with the light pen:

The following prompt will then appear in the lower right corner of the screen:

```
YOU HAVE A CHOICE OF 4 GRAPHS AND/OR NUMERICAL DATA.
#1 = ''GALLONS SUPPLIED VS SITE #.''
#2 = ''MOST EFFICIENT SUPPLY PT.''
#3 = ''MOST COSTLY SUPPORTED UNIT.''
#4 = ''DISTANCE TRAVELED VS SOURCE.''
#5 = ''INDIVIDUAL ANALYSIS.''
#6 = ''RESUME LIGHT PEN CONTROL.''

ENTER NUMBER SELECTED?
```

Figure 2. Display Analysis Menu

All of the DISPLAY ANALYSIS subroutines are controlled using the keyboard as the input device.

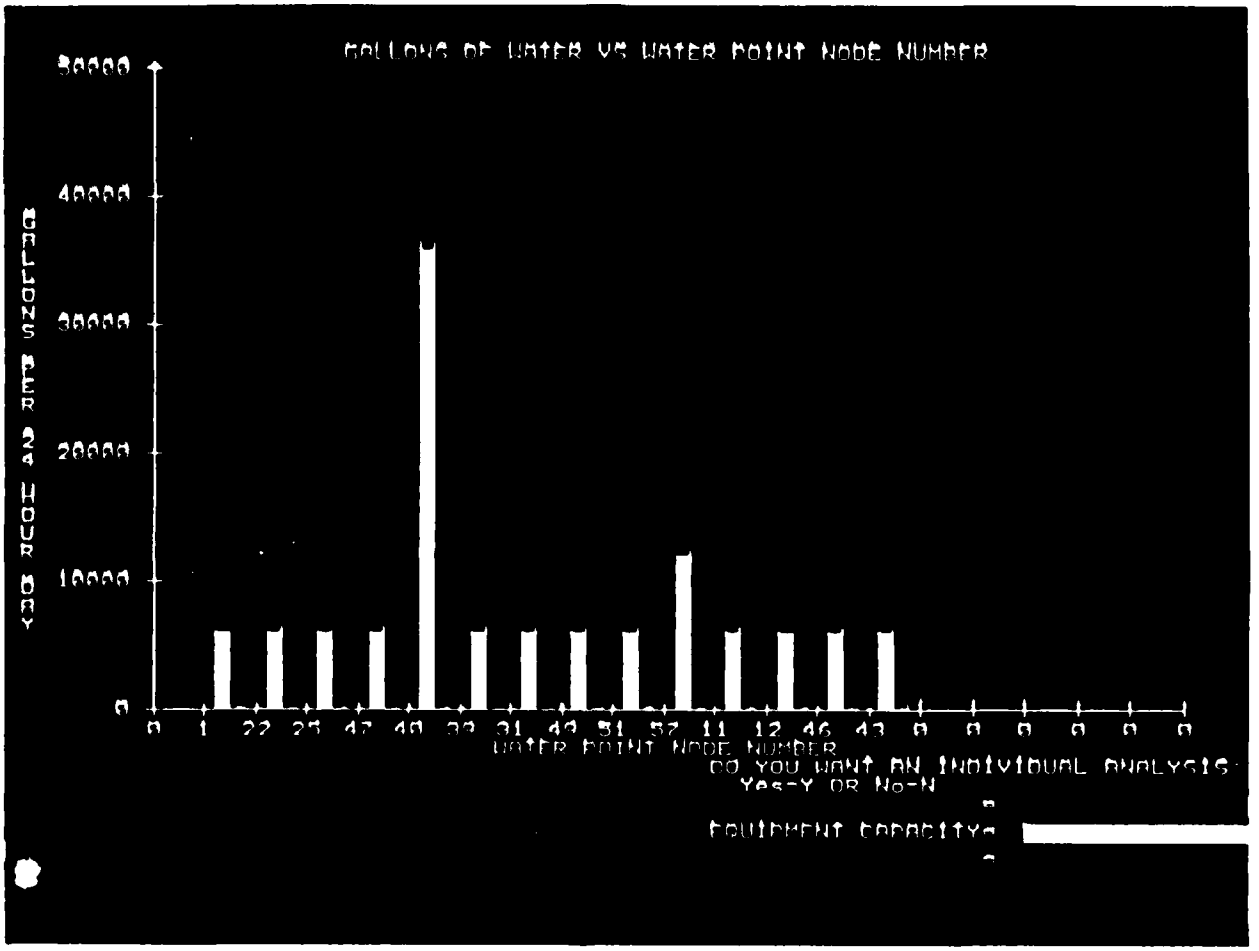


Figure 3. Gallons Supplied vs Site #

The first graph, #1, is the actual demand upon respective water points in comparison to its potential capacity if more equipment sets were allocated. Three bars are plotted for each water point. The green bar is the capacity of the potential water site's source to provide water, e.g., wells, rivers, etc. The yellow bar is the capacity of the water point's purification equipment, given design limitations and the number of equipment sets allocated to that site. The red bar depicts the consumption of water from that water point site by the supported units. This graph is intended to identify any sites not being utilized and any whose production capacity could be increased by the addition of more equipment sets.

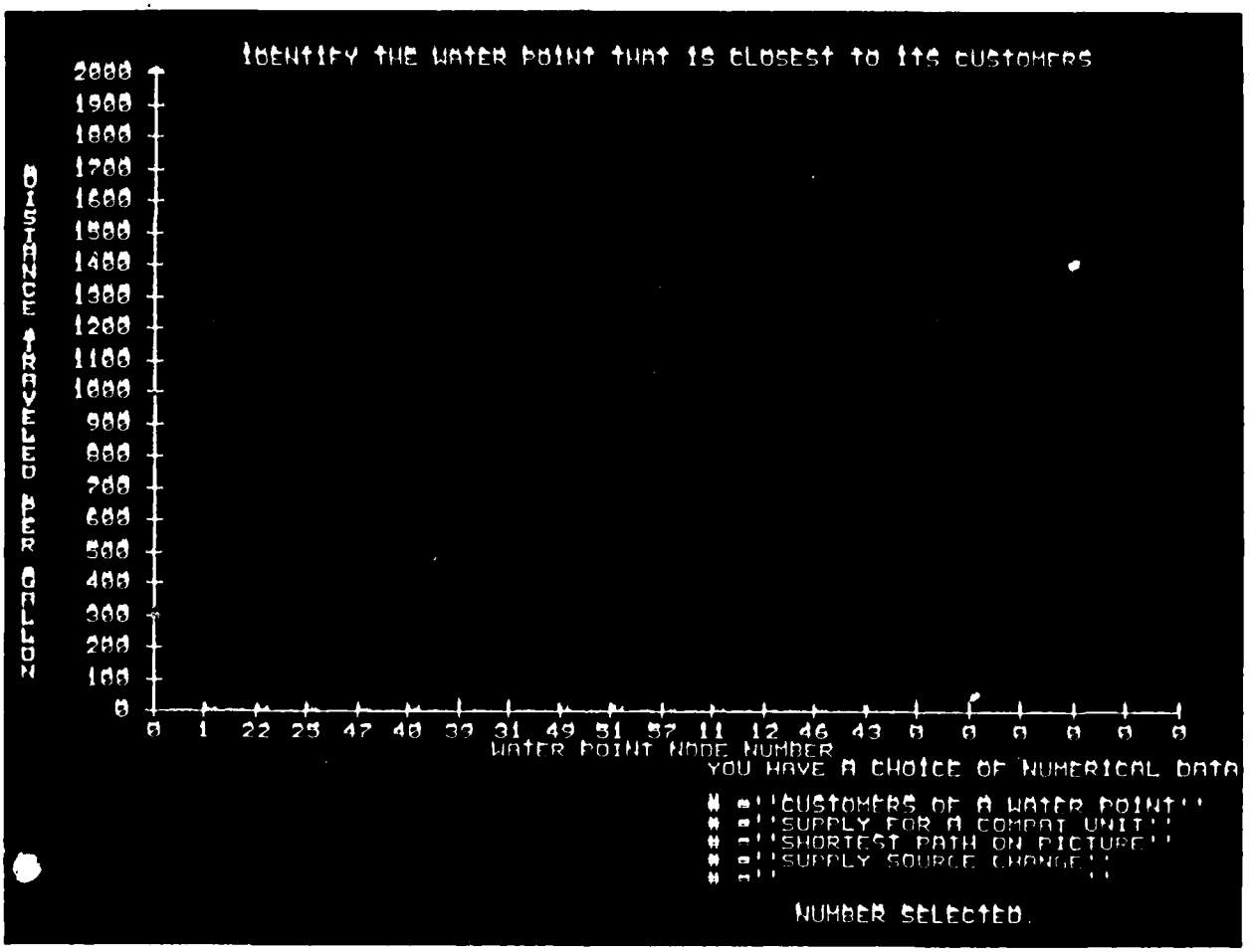


Figure 4. Most Efficient Supply Point

The second graph, #2, is the ratio of the total distance traveled by the customers of a water point to the number of gallons of water that point produces. Distance for each water point is summed over only those supported units drawing from that water point. This graph is intended to identify the most efficient and the most uneconomical water points, i.e., the smaller the ratio the closer the supported units, and vice versa.

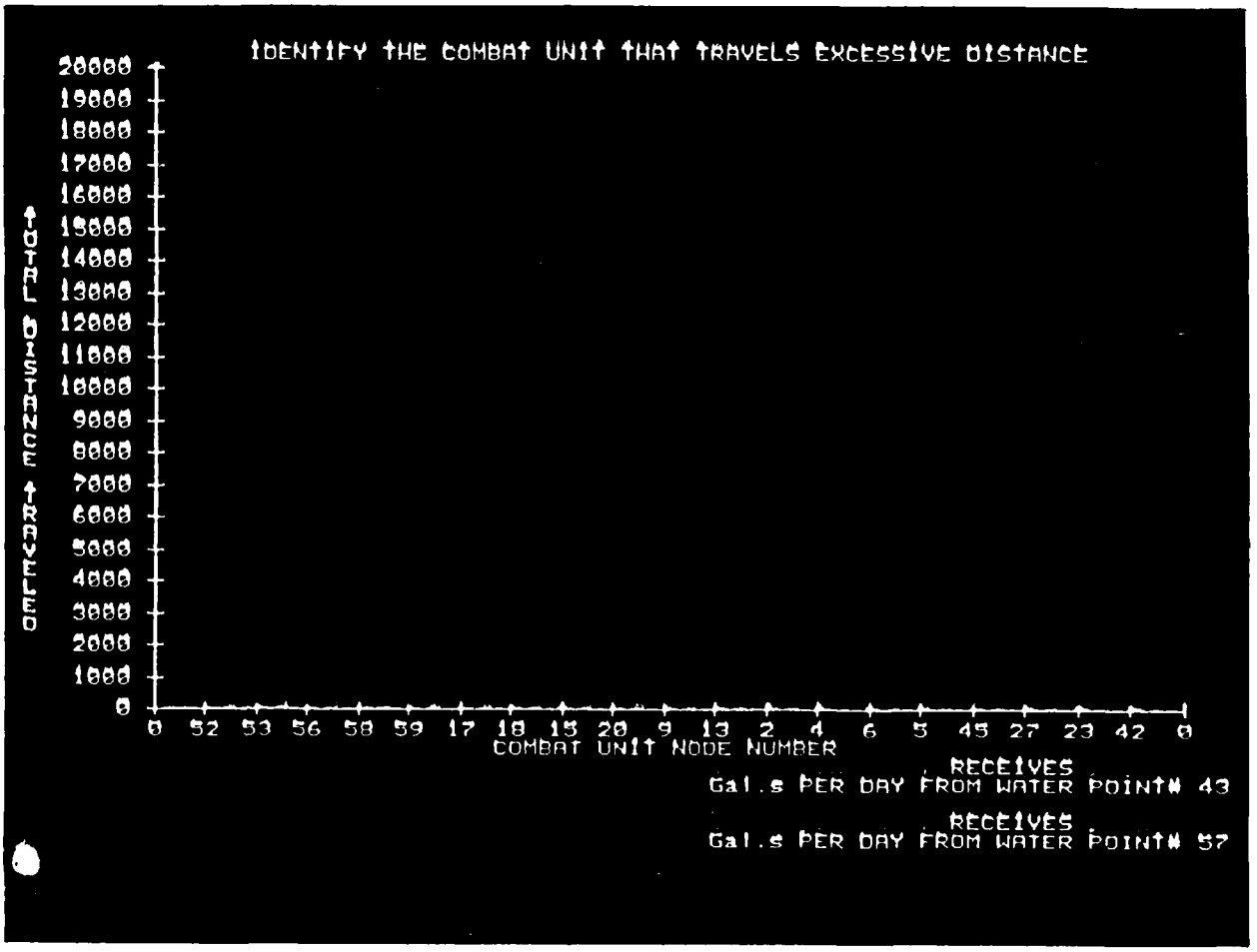


Figure 5. Most Costly Supported Unit

The third graph, #3, has two bars plotted for each supported unit. The red bar reflects the total distance traveled by each supported unit in obtaining its required quantity of water. The green bar is a ratio of that same total distance to that supported unit's required quantity of water. This graph is intended to identify the supported units that have to travel the farthest distances.

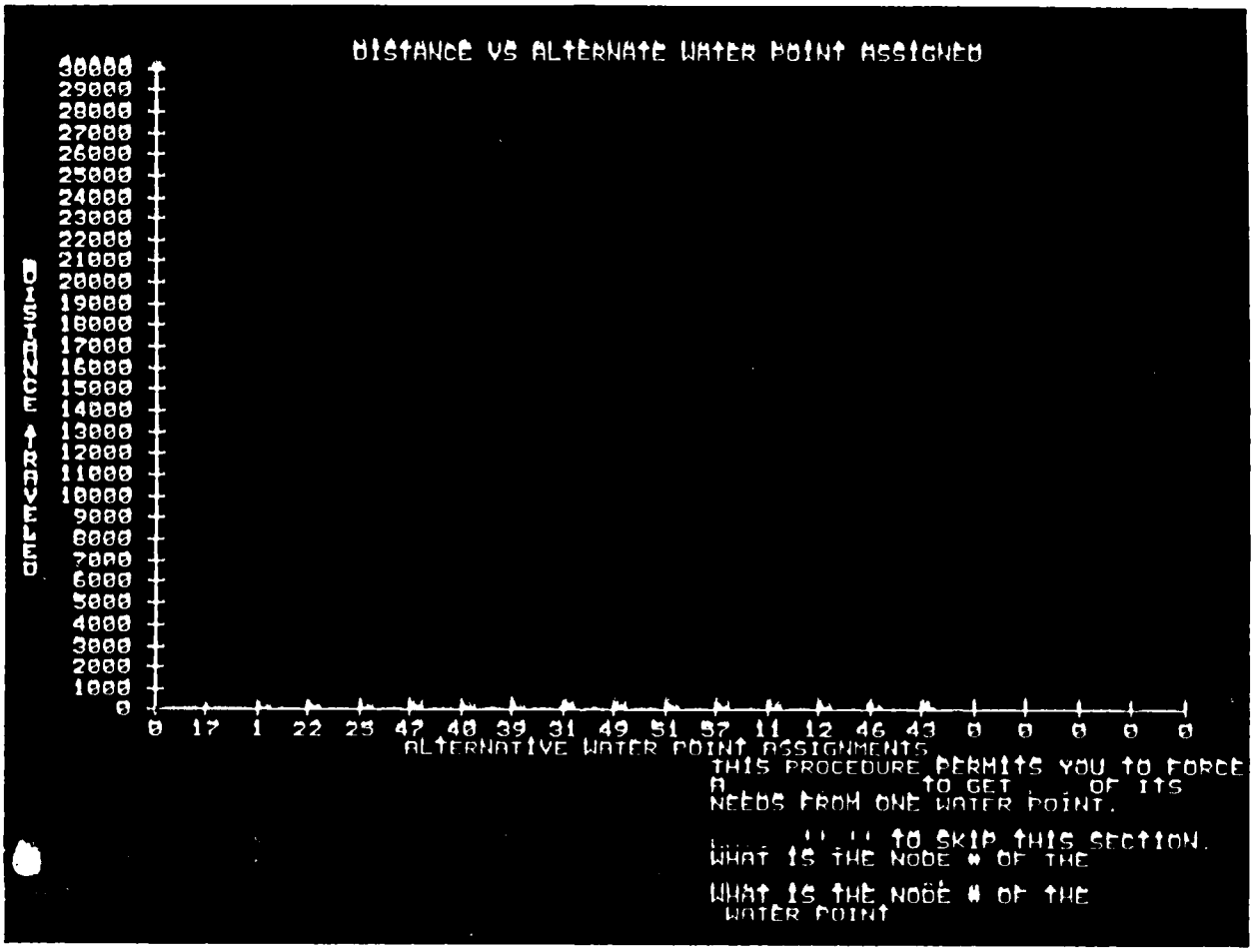


Figure 6. Distance Traveled vs Source

The fourth graph, #4, is actually a series of different graphs that can be requested, one for each supported unit. The dark blue represents the distance traveled by that supported unit if no changes are made. The magenta depicts the increased or decreased distance that would be traveled by that unit, if it received all of its supply from any of the other water points. This graph is intended to select that water point that would best serve a particular unit if all other units are ignored.

The individual analysis, #5, provides several options. It may be selected concurrently with any graph to verify or explain any particular result observed. These same data provide the final solution once the analysis is completed and the actual locations selected.

The following prompt will appear in the lower right corner of the screen:

```
YOU HAVE A CHOICE OF NUMERICAL DATA.
#1 = ''CUSTOMERS OF A WATER POINT.''
#2 = ''SUPPLY FOR A SUPPORTED UNIT.''
#3 = ''SHORTEST-PATH ON PICTURE.''
#4 = ''SUPPLY SOURCE CHANGE.''
#5 = ''RETURN TO GRAPH MENU.''

ENTER NUMBER SELECTED?
```

Figure 7. Individual Analysis Menu

The shortest route between any two nodes in the network may be plotted by selecting Individual Analysis item #3, Shortest Route.

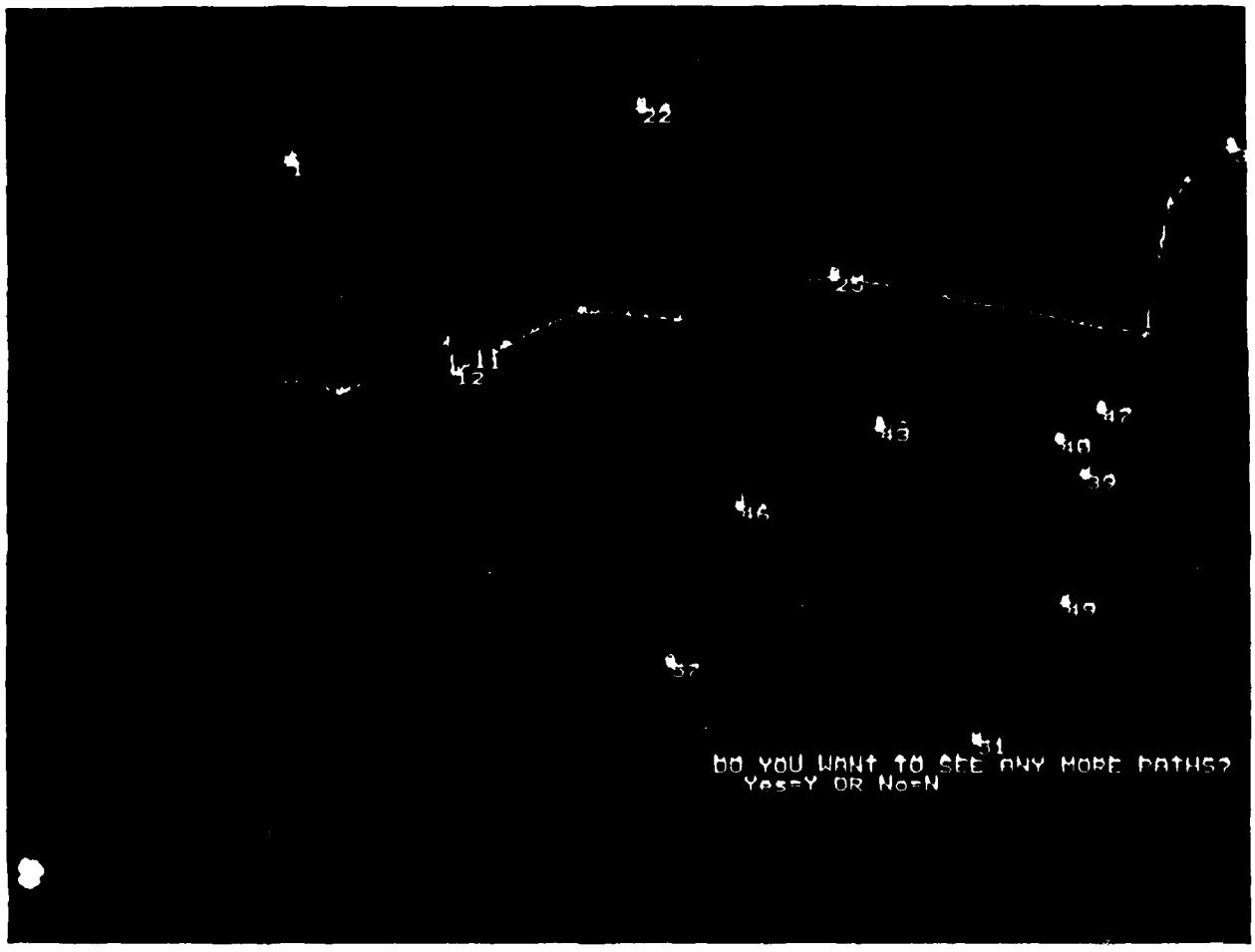


Figure 8. Shortest Route

In addition, the individual analysis routine #4, allows an individual supported unit to be selected to receive all of its supply from a particular water point. All subsequent graphs would then reflect this change. (To return to original conditions it is necessary to recompute the flow.)

The following prompt will appear in the lower right portion of the screen if the RESTART menu point is selected with the light pen:

```
#1 = ''COMPLETE RESTART''
#2 = ''MAJOR RESTART''
#3 = ''MINOR RESTART''
#4 = ''RETURN TO LIGHT PEN CONTROL.''

ENTER YOUR SELECTION?
```

Figure 9. Restart Menu

The RESTART light pen menu item provides three capabilities. The first item, #1, executes a complete restart. A complete restart requires the user to trace in a new road network. The old network is not destroyed, it is only erased from the screen and may be recalled by initiating the NTRACE program. ALWAYS place a disk containing only system files and programs NTRACE and COMPUTE in disk drive #1 before tracing in a new road network. (The disk does not have sufficient memory space to store more than one road network picture at a time.)

A minor restart, item #2, erases the current supply and demand capacity values and permits the changing of the constant values. A major restart allows all of the data existing under one name to be assigned a new problem name and copied to a second disk. (The

original data is not destroyed. Only a duplicate is made under the new file name.)

After analysis for a given set of open water points, the user may return to the data input portion to make changes in the number and capacity of water points. The flow must then be recomputed (COMPUTE FLOW) and another analysis of the results performed.

An attempt was made during the writing of the code to make the procedure as "forgiving" as possible. The combination of video and message prompts should lead anyone with a rudimentary knowledge as to what is important for the location of military water points through the solution procedure.

At key points the operator is required to respond to YES or NO prompts. This requires a keyboard entry followed by pressing the RETURN key. If RETURN only is pressed in response it will be accepted as a NO response to the prompt. Only the letter Y need be entered to imply a YES response.

After each graph is drawn the user is prompted for a numerical data request. This is particularly useful in explaining or clarifying graphical results that may have impact on the location selection.

The entire program was written in such a manner that a carriage return or null response to any of the DISPLAY ANALYSIS input prompts will cause that subroutine to be skipped. This also enables any user who becomes "lost" in his analysis of the data to always return to light pen control by entering multiple carriage returns. The prompt, LIGHT PEN ACTIVATED, will appear when the user has left the DISPLAY ANALYSIS package of subroutines.

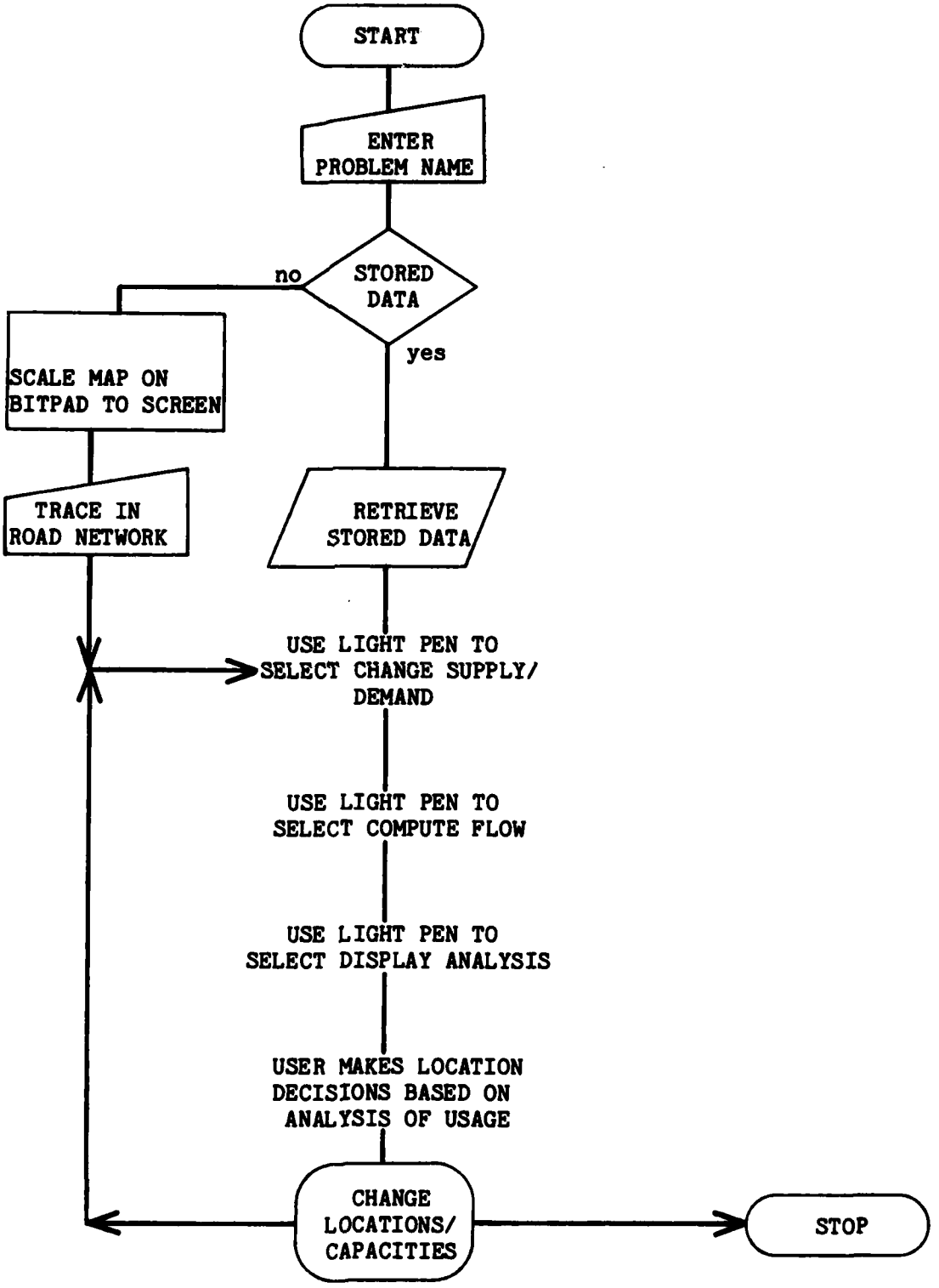


Figure 10. Flowchart of User Actions

CHAPTER IV

IMPLEMENTATION AND DOCUMENTATION

Instrumentation and Equipment

The primary item of equipment utilized in this research is the Chromatics color graphics minicomputer.[43] It is a complete, self-contained, high-resolution (512 X 512 dot matrix) color graphics terminal with an integral Z-80 microprocessor, attached floppy disk drives and 64K bytes of random access memory. Its high resolution screen provides a choice of from one to eight colors and automatically generates geometric figures.

In addition, the terminal is equipped with a light pen. This is a device that can detect light on the screen and feed a signal back to the terminal. This signal is used to determine where the pen is located in relation to the screen. This is the primary device for controlling program execution.

A digitizer pad is utilized to input the visual representation of the road network.[5] This accessory to the terminal converts graphic information into digital form suitable for use by the Z-80 microprocessor. It is utilized by positioning crosshairs or touching a stylus to any position on a map that is affixed to the pad's surface. The x,y coordinates of that position are transformed into their digital equivalents and transmitted to the terminal for processing.

Implementation

All programming was accomplished using Chromatics Basic Language.[8,9,13,43] The primary blocks are: (i) map data input, (ii) menu selection control, (iii) general purpose data input, (iv) data manipulation, (v) computations execution, and (vi) display of the results.

Due to the size of the program, approximately 1000 lines, the program was divided into two separate programs. Program NTRACE controls data entry and manipulation and calls the COMPUTE program. NTRACE provides light pen selection of menu items: ADD NODE/ARC, STOP OR SAVE DATA, CHANGE SUPPLY/DEMAND, and RESTART. A selection of menu items COMPUTE FLOW or DISPLAY ANALYSIS while under the control of program NTRACE, results in all accumulated data being saved on disk and program COMPUTE being retrieved from the disk and execution initiated.

Program COMPUTE performs all calculations and controls the display of the results. COMPUTE provides light pen selection of menu items: STOP, COMPUTE FLOW and DISPLAY ANALYSIS. While under the control of program COMPUTE, a light pen selection of menu items ADD NODE/ARC, CHANGE SUPPLY/DEMAND, and RESTART results in chaining back to program NTRACE for subsequent execution. The results of the calculations are not saved on the disk; COMPUTE FLOW must always be executed prior to DISPLAY ANALYSIS, and is automatically chosen if the user elects to ask for analysis when no results of flow computation are available.

Throughout both programs the intent was to make them as foolproof as this researcher's ingenuity would permit. It is intended to be possible for one to operate the entire program with no background as to what the correct solution procedure is.

Data Storage and Manipulation

The primary array is one for general purpose storage. This array, NN, is the only array that is not dynamically dimensioned based on the maximum number of nodes in the problem, variable name MA. NN is utilized to store the limiting parameters of the problem and its values are used to dimension subsequent arrays. Another use of NN is in testing to see if the operator is performing solution steps that are improper. The program checks for the existence in NN of various stored values needed to perform requested procedures; either execution is allowed to proceed, control is shunted to a prerequisite procedure, or the user is prompted as to what can be done.

The IF statements to check for variables having values greater than zero are of the form IF ‹variable› THEN ‹line number›. Any value other than zero results in the appropriate branching of the program in order for execution to proceed. A value of zero is interpreted by the machine as a signal that data needed for continued execution does not exist.

The largest memory requirement comes from the storage of the data input from the map using the BITPAD digitizer. This data is stored in three different arrays. The main one, D(I,J), stores the distance from any node I to any node J that are joined by an unin-

terrupted arc. This value is stored as a two way arc so it is only necessary to trace each road section once. Array D(I,J) is dimensioned to be the same size as the number of nodes in the problem. That is for the maximum of 60 nodes, D(I,J) becomes a 60x60 matrix. Since 60x60 is the largest array that the Chromatics can handle, this is the constraint on the maximum number of nodes. (Use of a linked list can greatly increase this maximum in future implementations.)

The other two arrays are NX and NY. These store, respectively, the screen's X and Y coordinate of each node. They are by necessity dimensioned to be the same as the number of nodes, variable name MA. Arrays NX and NY are used to plot the change of the node colors on the screen.

The search for an efficient shortest path algorithm resulted in the next set of arrays. A shortest path algorithm by Pape[15,41] required input to be in forward star format. This utilizes three arrays, NS, NT and AL. They are generated from the D(I,J) matrix and stored for use by program COMPUTE. In simple terms, they compress all of the zeros representing nonexistent arcs out of the D(I,J) matrix. This greatly reduces the amount of memory required and also permits rapid access to the next arc when finding shortest distance paths. A relatively sparse network is assumed, with the average number of arcs per node being less than five. This only affects the dimensioning of the linklist arrays, NT and AL.

The input of data for the respective water point nodes and combat units resulted in four arrays. Two of them are pointers to the

nodes that are water points or sources, array SR, and nodes that are supported units or sinks, array SK. Array Q stores the capacity of each water site designated and the demand for each supported unit. It is dimensioned to be the maximum number of nodes and therefore has the capability to store a capacity for every node in the network. This prohibits the designation of a node as both a demand location and a supply location. Array IS stores the capacity of each water point based on the minimum of either the equipment or that site's source of water.

This completes the data base needed for all calculations. All subsequent arrays and matrices are dimensioned based on the number of water points and the number of supported units. These values are stored in variable names NN(7) and NN(8) respectively.

The transportation algorithm requires a cost matrix, IC(S,T), that contains the shortest round trip distance from each water point to each supported unit. A dummy supported unit is created to consume the excess supply at the last column position. The results from the transportation algorithm are stored in a compacted tree structure.[39]

The plotting routine utilizes three arrays, X,Y and NP. X and Y store the values to be scaled for the respective coordinates. NP stores the numbers to be plotted as node numbers on the X axis.

Menu Operation

The menu selection routine uses two different identifiers to make a selection of the action to be initiated. They are the value of variable name HT and the location of the light pen hit on the screen.

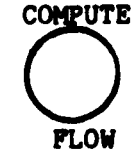
The value of HT is alternately assigned integer values to be used in the ON HT GOTO ··· statement. This insures that if a hit is made on the screen in the wrong place for the section being utilized, it will be ignored. In addition it branches the interrupt back to the correct line in the program for continued execution.

If HT=1, then the menu points are allowed to initiate new action. Otherwise, hits in the menu section will be ignored.

HT=5 for network data input
HT=6 for termination of digitizing.

HT=1 menu hit is allowed

HT=2 for water point data input
HT=3 for supported unit data input
HT=4 for change in problem size



HT=1 menu hit is allowed
"Light Pen Inactivated"
(Until Completion)

HT=1 menu hit is allowed
"Light Pen Inactivated"
(Until Completion)

Add Node/Arc

The ADD NODE/ARC subroutine will be automatically entered each time a new road network is being traced in. When this subroutine is being executed the message, "DIGITIZER ACTIVATED," will appear in the lower right portion of the screen. Once this message appears the user must insure that there is a disk with sufficient space available to store a PIC file, 300 sectors, mounted on the drive being utilized. Otherwise the system will try to store data where no space exists.

In addition to entering a new road network, this subroutine may be chosen when the user wishes to make modifications to the existing network. By selecting ADD NODE/ARC with the light pen after a network has been entered and saved on disk, the user can then specify the distance of any arc by over-writing the stored data, e.g., set an arc to zero if a road was destroyed. Caution must be exercised, in that all arcs are stored as two-way distances. Therefore, to completely cancel out an arc from the network the distance from the start to end point and vice versa must both be set to zero. Also, if only a one-way distance is set to zero the program will still allow travel in the opposite direction when calculating shortest paths, so overall effort is no longer minimized. If the user anticipates ever restoring the original distances they must be recorded and reentered.

Compute Flow

Three computational actions take place during execution of COMPUTE FLOW.

First is the computation of the shortest paths from each of the

water points to each supported unit respectively. These are first stored in a matrix and then upon termination of the program, are stored on disk. This shortens the time needed for the program to perform subsequent analysis of the saved data. Approximately 30 seconds per water point node for a 60 node problem is required for shortest-path computation.

Second is the search through the potential site capacities and all of the unit demands for an initial solution. This is necessary in order for any optimization to take place. Approximately 30 seconds is required for the initial solution.

Third is the application of the transportation algorithm to this initial solution. The transportation algorithm repeatedly modifies this initial solution in such a manner that the total distance traveled by all of the supported units in getting their water is reduced at each iteration. Approximately 10 seconds is required per interation.

Display of the Results

This section contains several subroutines that act as data manipulators. They utilize as input the data from the COMPUTE FLOW calculations and call upon a graphing routine to display the results.

This is an entire package of subroutines that allow access to other packages of subroutines. It is as flexible and useful as the user's imagination will allow. See Chapter III for a more detailed description of its use.

Restart

The RESTART section is a general purpose function that should have intuitive appeal to the user. To a user totally familiar with the program and the system commands of the Chromatics it is an unnecessary routine. Once a user has decided to change the number or capacity of either the supported units or water points a MINOR RESTART may be requested. This transfers execution back to program NTRACE for the change of the problem's initial constants.

The MAJOR RESTART routine allows the user to start a new problem with a new name using a data base previously input under a different name. This would be useful if the user wishes to retain all of the data associated with a particular set of locations. Note: Any changes to one particular problem require at most a MINOR RESTART.

A listing of the actual code with appropriate comments may be found in Appendix VI AND VII. The code is internally documented with comment statements.

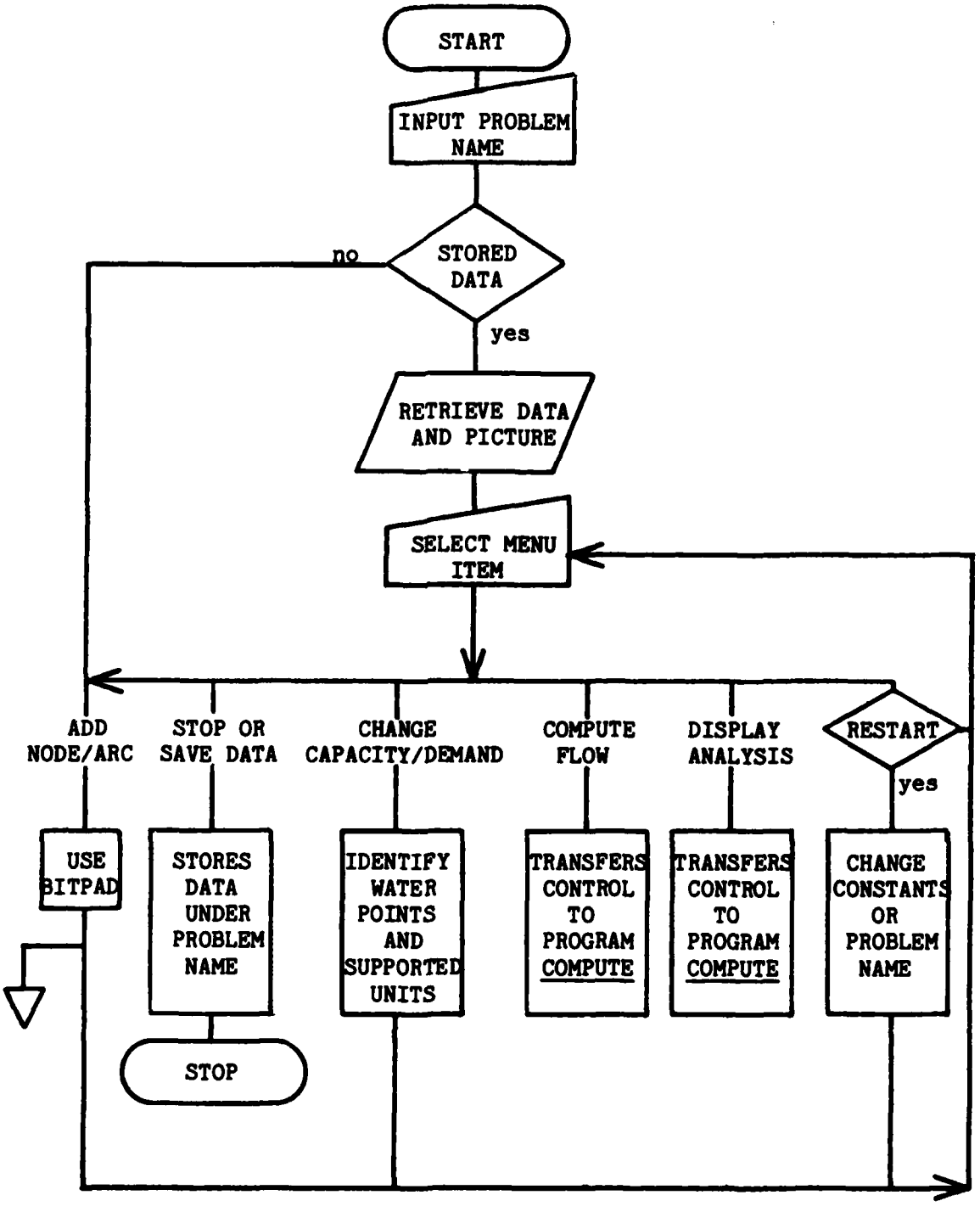


Figure 11. Flowchart of Program NTRACE

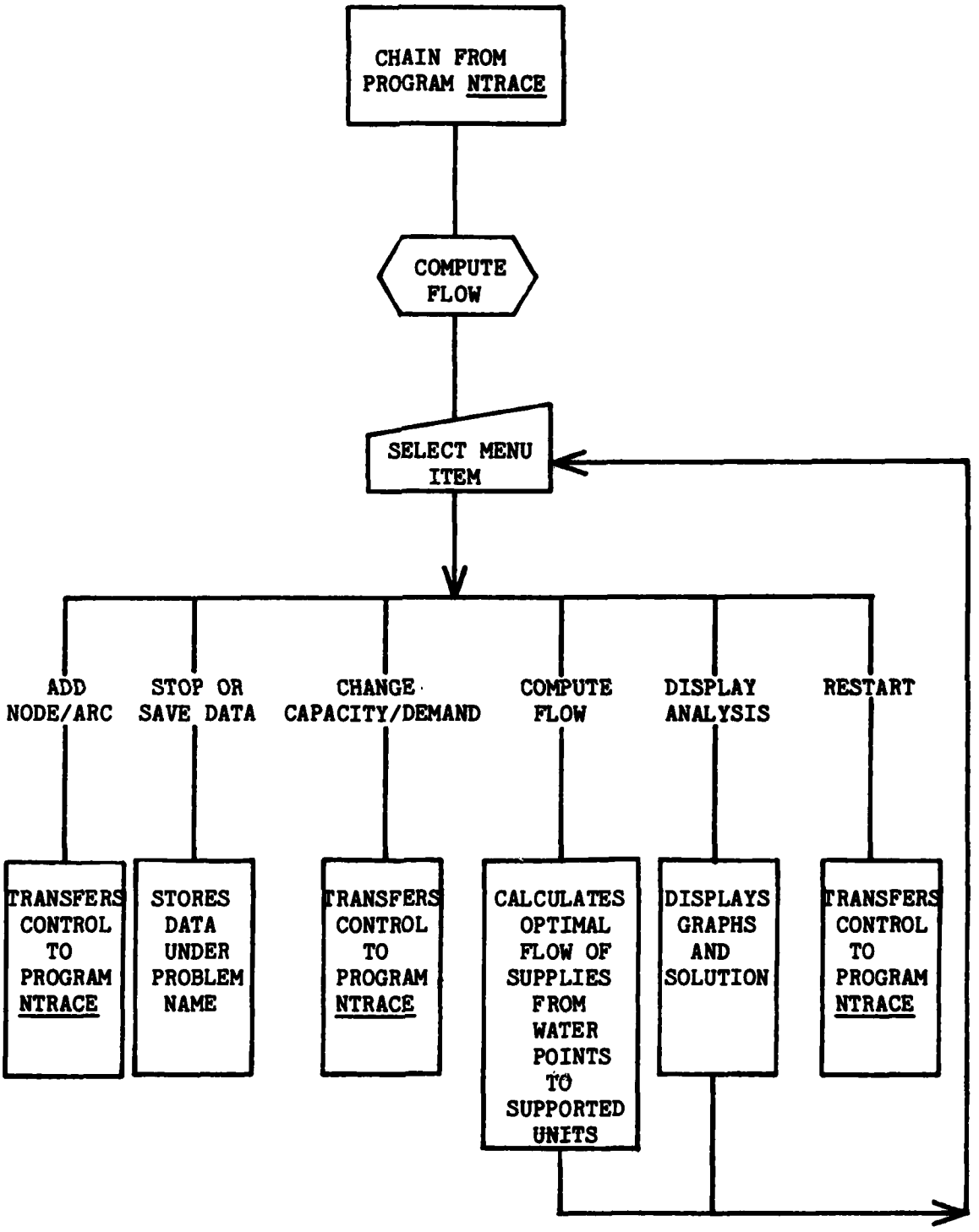


Figure 12. Flowchart of Program COMPUTE

Procedure

This Decision Support System was designed to be interactive. That is, it requests data from the user using sentence structure together with visual prompts. These assist the user in entering the needed data at the proper time. In most instances an erroneous entry will be ignored and a new request for the same data initiated. In other cases the results of the entry will be displayed visually. It is up to the user then to identify that an erroneous entry has been made and correct it by reentering the correct data. Only the most recent entry will be remembered by the system.

The program will not function unless a data base is first created and stored for subsequent processing. The required data base is input to the terminal using the digitizer pad. First the area of operations is determined and a map sheet of appropriate scale selected. The entire area must be no larger than the ten inch by ten inch tracing area on the digitizer pad. If a map of sufficiently large scale is not readily available, then a smaller map may be adapted by employing a reducing reproduction machine.

The program will prompt the user as to the correct method of scaling the area selected so that it will be proportionately displayed on the screen.

When the scaling is complete, the road, rail or any similar set of movement routes may be traced. Due to the extreme difficulty in having a computer recognize the intersection of roads, all portions of the road traced must start and end at a node. Correspondingly, the

user must first designate all supply points and demand points as nodes. A node is just another name for a start point or an end point.

Since it is desirable that all possible paths or routes of travel between the supply points and demand points be considered in the solution, each potential route must be traced. It can be readily visualized that for even small problems the potential number of routes from each supply node to every demand node can result in an unmanageable number of segments.

The number of paths that must be traced to connect each node to all possible routes is greatly reduced by designating road intersections as nodes. This allows the computer to treat that intersection as a switching point so that supplies can flow in and out of it in any direction.

The four button cursor is used to designate the nodes and trace the adjoining roads. The BLUE button designates nodes and the GREEN button draws the arcs. The GREEN button must be depressed continuously as long as a road is being traced. As soon as it is released the terminal searches for the closest node. When it does not find one within 25 dots of a previously designated node it will establish one.

A road that is traced erroneously may be simply retraced. Only the most recent input is retained. Caution must be exercised in the designation of nodes. It is not possible to delete a node once it has been entered without restarting the entire digitizing procedure. Approximately 30 minutes is required to accurately digitize a 60 node

network containing 200 arcs. This procedure is recognized as being awkward. See Chapter V, Recommendations, for suggested improvements.

Once all nodes and arcs have been entered the picture and data entered will be saved before allowing execution to proceed. This precludes having to digitize the map data a second time if time does not permit a complete analysis at once. Once the initial data has been saved, the program may be stopped and restarted without loss of continuity by selecting STOP with the light pen. Note: During the execution of the CHANGE SUPPLY/DEMAND, COMPUTE FLOW and DISPLAY ANALYSIS the light pen is turned off. All ongoing calculations must be terminated before it is reactivated.

To resume program execution once the data has been saved, it is only necessary to mount the storage disk on DRIVE # 1. Then type in DOS"LOAD NTRACE" which, after execution by the Chromatics, will result in OK appearing on the screen. Now type RUN, followed by a carriage return, and follow the given instructions or answer the prompts.

Once the network data has been entered, the supply and demand nodes or water points and supported unit locations, respectively, must be designated. This is accomplished by selecting the CHANGE SUPPLY/DEMAND menu point. The prompts that appear will guide one through this procedure. All possible water points and all possible supported unit locations must be designated at this time if they have capacities greater than zero. A failure to provide sufficient supply to satisfy all demand will initiate a prompt to start over. Note:

When making changes in the capacities alone of a previously designated set of supply/demand points, a negative entry is required for termination.

After the supply and demand nodes have been designated, the COMPUTE FLOW menu item may be calculated. The results of these calculations are needed before the DISPLAY ANALYSIS routine can be entered. This is accomplished by selecting COMPUTE FLOW with the light pen. While executing computations the light pen is inactive to prevent interruption of the successive calculations. If the shortest-paths have not been calculated for the present data set, a prompt will appear informing the user that this is being done. This is followed by the initialization of the transportation algorithm and its subsequent optimization.

At this point the user is ready to conduct the analysis of the potential sites selected for consideration. See CHAPTER III for details.

CHAPTER V

EXPERIMENTAL RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Experimental Results

The example water point location problem that was implemented was provided by the U.S. Army Engineer School, Ft. Belvoir, Va. This hypothetical situation is used by the Engineer School to instruct company grade officer students during the Operation Windup phase of instruction in the Engineer Officer Advanced Course.[1]

The map used for input is the same as that referenced in the operations order, AJO, 1:250,000, ARIZONA, Sheet NI 12-10. The roads traced were the secondary and primary road network in the area of concern. All roads are two-way.

Army TM 5-700 was used to provide all data pertaining to Water Point equipment and location criteria.[18] In addition, it furnished the demand data in terms of gallons per man per day. Due to the Arizona location, the climate was taken to be desert environment, requiring five gallons per man per day.

Personnel strengths of the units were computed based on the authorization given in FM 101-10-1.[49] The estimated demand for one gallon per day for each vehicle was included by rounding up the needed quanity of water for the men to the next largest trailer load.

The solution procedure of the Operation Windup case problem proceeded as follows:

Since the entire map sheet could not be digitized on the BITPAD digitizer, [5] a hypothetical area of operations was chosen. This chosen area was then reduced on a copy machine so that its road network could be contained in a 10" x 10" area.

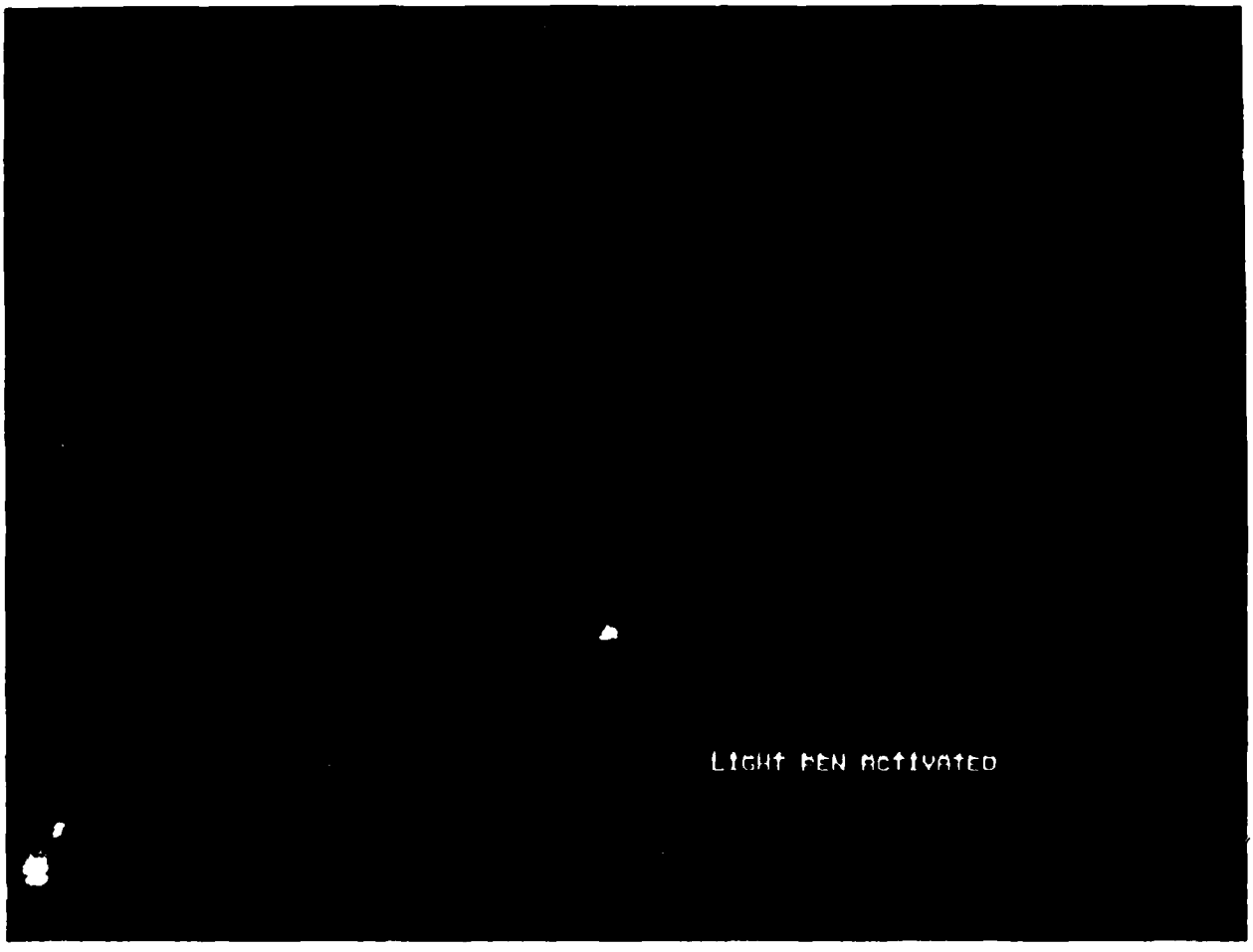


Figure 13. Digitized Road Network

After digitizing the network and before designation of the supported unit locations and potential water point sites the screen will appear similar to this.

The maneuver units and respective headquarters elements listed in the operations order were then deployed to field locations that would simulate the military situation. This resulted in 15 battalion size combat units and three brigade headquarters elements. Headquarters units are located at node numbers 5, 18, 42 and 53. Mechanized Infantry battalions are located at node numbers 4, 13, 17, 23, 45, 52, 58 and 59. Armour battalions are located at node numbers 2, 6, 9, 15, 27 and 56. The demand for the Cavalry was arbitrarily placed at node 20. Other combat service support units listed in the operations order were assumed to be part of the divisions rear element which would be a separate problem.

The units were all assumed to be at full strength. This resulted in the Mechanized Infantry and Armour battalions having respective strengths of 880 and 548 personnel and the Cavalry, 875 personnel. The brigade headquarters elements were given a strength of 372 to simulate the inclusion of elements of the direct support Combat Engineers, Field Artillery and Combat Service Support personnel together with authorized headquarters personnel.[49]

Fourteen wells were identified based on map symbols. They are located at node numbers 1, 11, 12, 22, 25, 31, 39, 40, 43, 46, 47, 49, 51 and 59. As per the special situation each well was taken to have two different capacities. With the exception of the Papago well, node

#59, each could produce at either 100 gallons-per-hour (GPH) continuously or at 500 GPH for 10-12 hours. The Papago well could sustain a continuous rate of 300 GPH or produce 1,000 GPH for 10-12 hours. All wells must set for 12 hours before pumping could resume if the maximum rate were pumped. The city of AJO water supply system could provide the division with 12,000 GPH.[1]

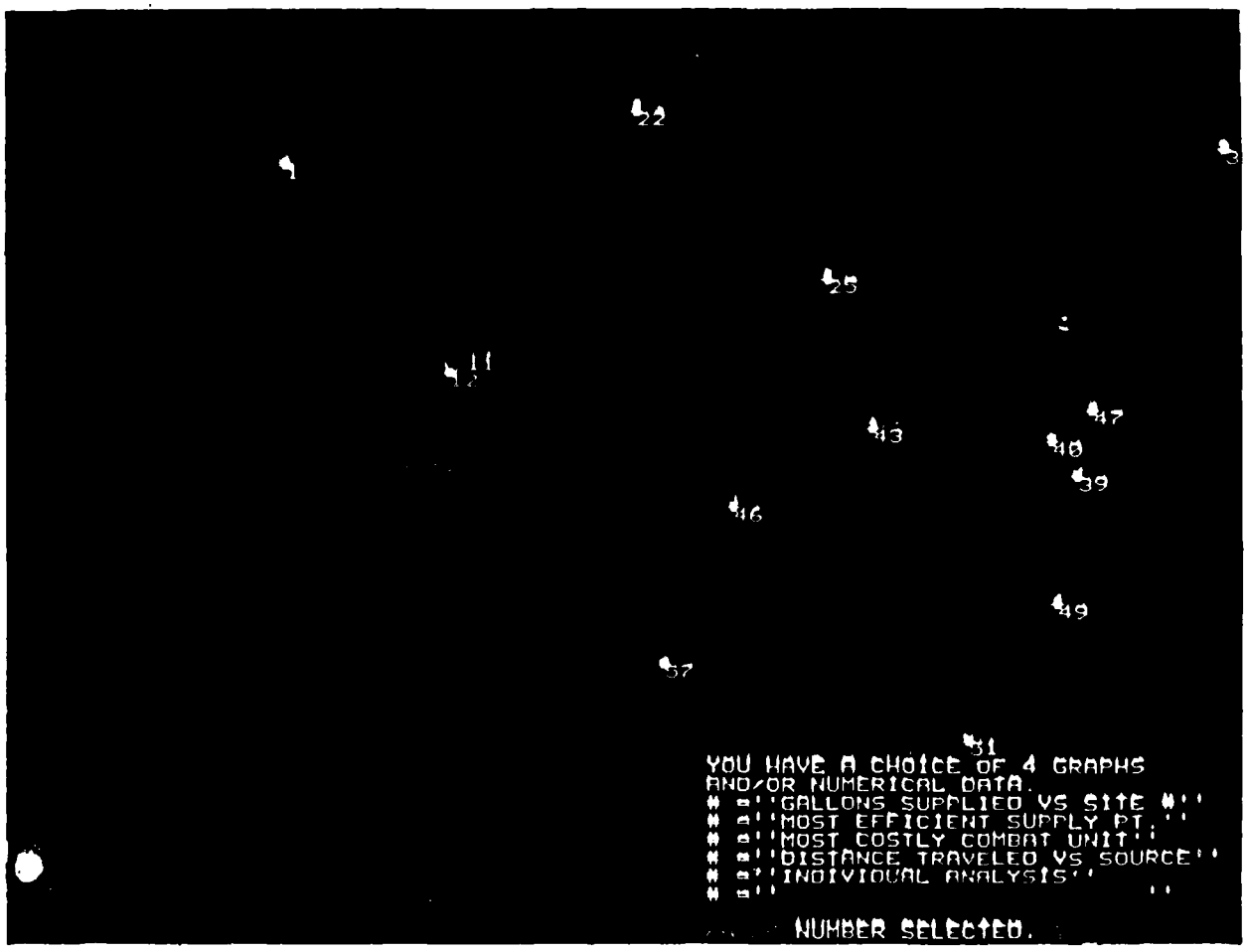


Figure 14. Digitized Network with Supply/Demand Nodes Designated

All other nodes represent road intersections or transshipment points. These were added to decrease the number of separate arcs that must be traced in order to represent all possible paths in the network.

Initially, all potential water point sites were assumed to be open or available for use at their continuous rate of production. This results in demand exceeding supply by 68 trailer loads of 400 gallons each. All water points were then increased to their maximum respective capacities. A value to enter for each water point was determined by multiplying the maximum rate of production times the average duration of 11 hours and then dividing by 24 hours. This gave a gallons per 24 hour day rate of 229 for all but the Papago well which had a new rate of 458 GPH.

To demonstrate the inclusion of nonstandard situations into the DSS the capacity of the water point at location #40 was arbitrarily increased to 2000 GPH. This is intended to simulate drawing on the city of AJO's water supply capacity.

After the calculation of the flow was complete the results were analyzed. Graph #1, Gallons Supplied VS Site #, showed that water sites #31 and 39 were not utilized and therefore should not be opened. See Figure 2, Chapter III, page 25. Additionally, water sites #1, 40 and 43 were operating at full capacity with sites #12, 49, 51 and 53 nearly at full capacity.

Graph #2, Most Efficient Supply Point, showed that water sites #1 and 46 are particularly desirable locations. See Figure 3,

Chapter III, page 26. This is because they are both close to their customers and operating at nearly full capacity. Water site #43 is a candidate for deletion if sites closer to its customers can be found.

Graph #3, Most Costly Supported Unit, showed that of all the supported units, the one at location #17 had to travel further than anyone else to satisfy its demand. See Figure 4, Chapter III, page 27. A request for numerical data and/or #5, Individual Analysis and subsequently item #2, Supply for a Supported Unit, gave its source of supply. There were 800 gallons from site #43, 3600 gallons from site #57 and 400 gallons from site #51.

Graph #4, Distance Traveled vs Source, showed that the supported unit at node #17 would have to travel slightly less distance if it were assigned totally to water site #57 which does have some excess capacity. See Figure 5, Chapter III, page 28. It would have to travel significantly less distance if it were to be served entirely by either water site #11 or 12. Since both 11 and 12 are already at full or nearly full capacity, only a forced assignment to water site #57 is feasible with the existing site capacity limitations. A request for numerical analysis and subsequently item #4, Supply Source Change, allows one to see effects of forcing supported unit #17 to get all of its supply needs from water site #57.

Upon the completion of the reoptimization, the results of this forced assignment can be readily seen by again requesting graph #1. Supported unit #59 is now served by water point #39 which was previously not utilized. Additionally, graph #3, shows that unit #17 still must travel further than anyone else to statisfy its demand. The conclusion is that a forced change of the supply source for unit #17 is not advantageous.

After deleting water sites #31 and 39 from the candidate list the flow is computed again. As expected all water sites are now being utilized. Also, since water sites #11, 22 and 47 are only partially utilized they could be operated at the sustained production rate of 100 GPH.

Conclusions

Solution of the Test Problem

After collecting the personnel strength data and entering it along with the road network an initial feasibility check was conducted. It was found that even with all 14 wells in the Division area operating at the sustained capacity there was insufficient water available. To satisfy the demand the water supply of all wells was increased to the highest production rate allowed. This is a realistic problem solving approach and was incorporated into the DSS by converting the 10 - 12 hour capacity to that of an average GPH capacity for 24 hours. The conclusion is that 12 water point equipment sets are needed to open and maintain the 12 water sites needed to satisfy the demand. Another solution would be to have one equipment set ser-

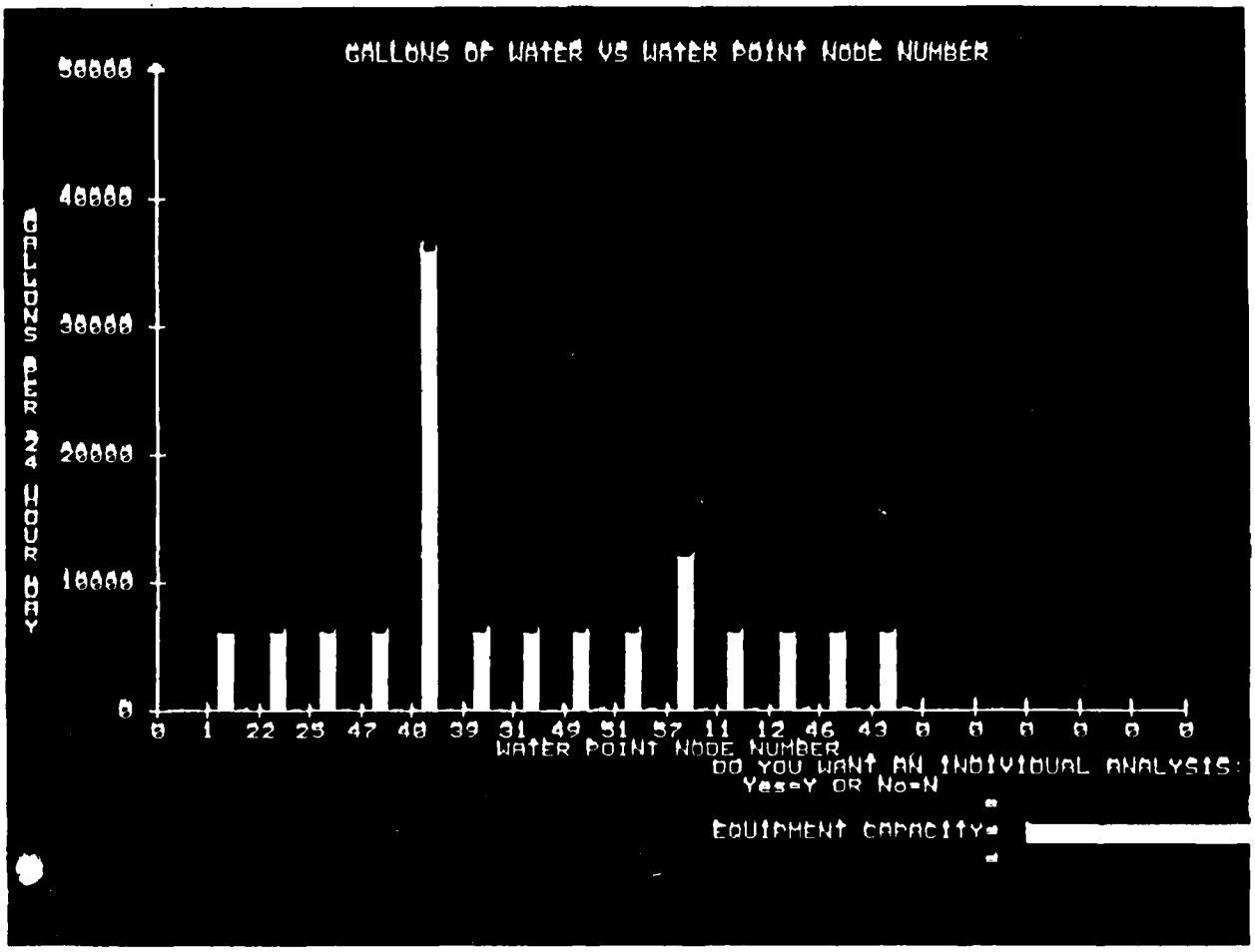


Figure 15. Forced Supply of Unit #17 from Water Point #12

vice two wells that are near to each other by employing its storage capacity and shuttling between two sites every 10 - 12 hours.

Since this case problem was prepared by instructors at the U.S. Army Engineer School, it is felt that its intent was to force all officer students to reach the same conclusion. As a training vehicle the students would learn that water resupply cannot be taken for granted as is usually the case.

The solution procedure is so flexible that the user should quickly feel at ease. This will insure that other uses will be found for the DSS demonstrated here, e.g., locating the best railheads to utilize in a combination railroad truck transport problem, choosing the location for ammunition resupply points, or selecting the location for the combat engineer's barrier material prestock points.

Solution Time

The following response times were measured for the 60 node case problem involving 19 supported units and 14 water points:

Background road network input:	30 minutes
Water Point Capacity Data:	2 minutes
Combat Unit Demand Data input:	4 minutes
Computation of Shortest Paths:	30 seconds per water site
Computation of Initial Solu.:	30 seconds
Computation of Optimal Solu.:	10 seconds per iteration
Analysis of the Results:	15 minutes

For larger problems all of these times would increase linearly with the number of nodes in the problem.

Recommendations

The following areas are presented here as potential enhancements of this prototype:

Digitized Map Input

(1) A more efficient data base structure to receive input from the digitizer pad is required. This would facilitate the use of several times as many nodes. Specifically, a linked list could easily be used here; arrays NS, NT and AL could be directly generated from the digitizer pad using a small amount of scratch storage.

(2) Considerable modification of the digitizing routine is needed to allow for the correction of mistakes while tracing the map. (An actual implementation would require that maps be predigitized on disks and available much as maps are now.) The digitizer would only be used to update the data on the disk based upon newly constructed roads. This predigitized map could conceivably include coded information as to classification of the different size roads.

(3) An addition of the military map reference grid to the screen would facilitate the input of both supported unit locations and potential water point sites.

(4) Standard military unit symbols could be depicted on the screen instead of node numbers to improve user orientation.

(5) A subroutine to permit the appending of adjacent map sheets by compressing the picture would significantly increase the versatility.

(6) The need to store a large picture file, 300 sectors, on the

disk could be eliminated if the road were stored as a series of arcs. This would then require only the storage of the end point coordinate pairs for each arc segment. This could perhaps be implemented by having two types of nodes.

The primary nodes would be recognized by the program as potential locations for water points, supported units and road intersections. The secondary nodes would only be used by the program to plot a representation of the road network. This would preserve user orientation and thereby supplement his subjective evaluation of alternative sites.

(7) An alternative means of entering the network could be by using the keyboard to specify the beginning node, ending node and distance. A preliminary implementation of this exists now by selecting the ADD NODE/ARC menu point with the light pen.

Supply/Demand Data Input

(1) Alternative means of entering the node data would simplify the initialization of the problem. For large numbers of nodes the switching between the light pen and the key board is awkward.

(2) Another interrupt routine could be set up to simplify the return to light pen control of the menu while in the node designation subroutine.

(3) The ability to have dynamic dimensioning of the number of supply points and water points in the problem would help the user feel more comfortable with the DSS.

(4) The overall color scheme of the network could be modified

so as to easily distinguish water points from the supported units, and both of these from the road intersections. Possibly the DSS should display no numbers by any of the nodes unless they are designated as either a supported unit or a potential water point site. The road intersections could be made the same color as the road to decrease clutter on the screen.

(5) It would be possible to store on the disk typical unit strength data and consumption data available for recall without consulting reference texts.

(6) A rearrangement of the data structure would also permit the collocation of supply points and demand points.

(7) A procedure for allowing the deletion of either water points or supported units from the candidate lists without having to re-enter all of the capacity and demand data is needed.

(8) The user should be able to recall, at any time, the data and the current solution.

Display of the Analysis

(1) The sensitivity analysis could be supplemented by heuristic optimization routines.[36,17,35] Also the possibility of calling on a host computer for an exact solution could be provided if appropriate communications channels were available.

(2) The scales of the graphs could be color keyed to the results and multiple scales plotted for each set of values.

(3) Simulated closing of a water point could be permitted by assigning all of its costs to the simulated infinity value of 32,000.

The "what if" effects of closing a water point could then be analyzed without returning to the CHANGE SUPPLY/DEMAND subroutine.

(4) The graphical results could be highlighted to bring out notable information, such as sites not used.

(5) A "HELP" subroutine could be implemented to explain each graph if the user is unfamiliar with the display.

(6) The availability of a procedure by which the user could identify the density of traffic on a specific arc would aid in preventing congestion on the road network.

(7) A subroutine to automatically weight the transportation algorithm cost matrix to favor supported units traveling excessive distances is needed. This could be accomplished by squaring all shortest-path distances in the matrix, or by setting any distances in excess of a predetermined maximum to infinity. The latter method would then prevent travel between those respective points whose distance has been set to infinity. Of these methods, the former would be more desirable due to its global effect on all supply transactions.

(8) By reducing the size of the graphs, all four of them could be displayed on the screen simultaneously to aid in their quantitative comparison.

(9) Maranzana's hueristic[31] would be particularly adaptable to this program's organization. It would be employed to select the sites that should be closed.

Overall DSS

(1) The color coding of all messages could be standardized to

increase the user's recognition of the response needed.

(2) The number of interrupt routines could be increased to handle errors that users are likely to make.

(3) Improvements in the specific wording of prompts could be implemented to decrease user irritation and increase intuitive understanding. A user experiment should be conducted to identify potential improvements.

(4) There are several possibilities for the distribution of this information to the supported units once a decision has been made. A printed copy of the actual supply sources with respective demand destinations could be provided on the standard line printer. By connecting the Chromatics terminal to a Xerox color copier, either paper copies or transparencies of any picture on the screen could be generated for distribution to supported units.

(5) The standardizing of the blinking throughout the program and perhaps its total replacement by a throbbing action would increase user orientation and decrease user irritation.

(6) A global refinement of this prototype is needed in order to bring it into line with the required consistency standards of a DSS, e.g., color usage, data input/output, user action minimization, and identifiability of user required actions or choices.

APPENDIX I

ASSUMPTIONS (A) AND THEIR JUSTIFICATIONS (J)

(i) A. An engineer reconnaissance has been conducted.

J. This is a routine engineer function.

(ii) A. The cost of water resupply is minimized if travel distance is minimized.

J. All relevant costs increase as the travel distance increases.

(iii) A. Unit demands and water point output are based on a 24-hour day.

J. Supply levels within the theater of operations are based on days-of-supply. One day-of-supply is a 24-hour operating day.

(iv) A. All water sites are located on or near existing roadways.

J. Ease of access is a prime consideration in siting a water point.

(v) A. All distances are determined from maps in equivalent units of measure.

J. Maps are available and give scaled representations of distances.

(vi) A. Each unit's demand for water is known.

J. Consumption rates per man and per vehicle are published in Army Technical Manual 5-100. Unit vehicle and personnel strengths are available from other Divisional Staff Officers. Within the operational area, consumption rates are adjusted to reflect most recent demands.

(vii) A. Capacities of all potential water sites are known.

J. Information would be available from the reconnaissance reports. See Appendix II for example reconnaissance report.

(viii) A. The number of available water point teams is known.

J. The Division Engineer knows how many water point teams he has. Additional teams can be requested from higher headquarters. Each team consists of a group of soldiers with appropriate water equipment sets to extract potable water from a water source.

(ix) A. The production capabilities of water point equipment sets are known.

J. Equipment capabilities for authorized equipment is available in Army TM 5-100. See Appendix IV.

(x) A. All water point teams have a storage capacity.

J. Each team has three storage tanks, each with 4,500 gallons of available capacity. See Appendix IV.

(xi) A. The capacity of each unit for water resupply is known to be 400 gallons per trip.

J. The only organic equipment for the bulk transport of potable water within divisional units is the 400 gallon water trailer. Each trailer is towed by a truck.

(xii) A. Round trip distances are more critical than one-way distances.

J. To effect water resupply, a trip must be made from the unit to the water point and back to the unit.

(xiii) A. Every time a unit conducts a water resupply trip, it acquires a full 400 gallon trailer of water.

J. It would not make sense to make a complete round trip for a lesser amount of water merely to make up the remainder of a unit's allocation. This results in the demand of each unit being rounded up to the next highest integer number of trips required to satisfy it. Likewise the capacities of each water

point are rounded down to the next lowest integer number of trailer loads that it has the capability to supply. (This may not be feasible if large capacity transport equipment were employed.)

(xiv) A. Any water site with an extremely large water capacity may be considered as multiple separate sites located side by side. Each capable of becoming water points.

J. Such a site will normally occupy a large area of terrain, and therefore be capable of accepting more than one water equipment set.

(xv) A. There is no fixed cost for opening a water point site.

J. Costs are "sunk costs". The equipment and personnel are on-hand and are assigned only the water point mission. They are not available for other missions. All other criteria for choosing one location over another will be taken into account by the users' interaction with the program.

APPENDIX II

ENGINEER RECONNAISSANCE REPORT AND WATER RECONNAISSANCE REPORT

The examples that follow were taken from reference [18], pages 18, 19, 20, 21, and 22.

ENGINEER RECONNAISSANCE REPORT
(TM 5-700)

PAGE 1 OF 1 PAGES

TO:	FROM:
CO 32nd Engr Bn	Hq + Hq Co. 32nd Engr Bn

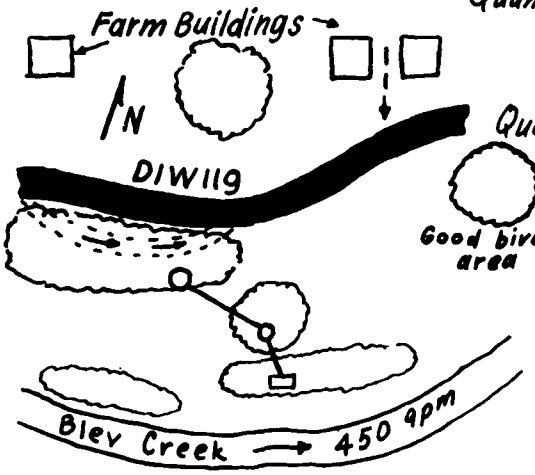
FILE NO.	PARTY LEADER (Name, Grade, Organization)	PLACE - HOUR - DATE
HS 47	Smith 1st Lt Hq + Hq Co 32nd Eng. Bn	Cq. 187256 - 070700 OCT.
REPORT NO. 1		

MAPS: France & Belgium; 1944; 1:50,000 Sheet 3855 II NW

DELIVER TO (Organization, Place, Hour and Date)
32nd Engr Bn, St Nicholas, 071100 Oct.

KEY	OBJECT	TIME OBSERVED	WORK ESTIMATE?
①	W	0835	YES

ADDITIONAL REMARKS AND SKETCH



Quantity: A = 2 sq. ft.
V = 30 fpm.
Q = 60 cfm, 450 gpm
Quality: slight turbidity
no odor
possible pollution from nearby farms
pH = 6.8
Chlorine demand = 2 ppm

Communications: 1-way road with good drainage runs to 1st Inf area. Not used for division supplies. Turnout at wp must be constructed.

Site Conditions: good concealment, no targets in vicinity ground slopes gently from road to stream, good drainage banks, 3' high, sodded. Use access road as parking area. Grove of trees or farmhouse can be used as bivouac for w.p. personnel.

Rating: Excellent w.p. for 1st Inf.

ENGINEER WORK ESTIMATE ON OTHER SIDE

TYPED NAME, GRADE AND ORGANIZATION	SIGNATURE
Norman H. Wells Capt. Hq & Hq 32 Eng Bn	Norman H. Wells

DA Form 1711-R. 1 Jun 61 Edition of 1 May 56 is obsolete.

Reconnaissance reports must be carefully prepared and available on time. The information presented must be legible, clear, complete, and concise. All information should be printed. DA forms 1711-R and 1712-R will be reproduced locally on 8 by 10½-inch paper.

ENGINEER WORK ESTIMATE

LOCATION KEY	DESCRIPTION OF WORK	UNIT REQ'D	HOURS	EQUIPMENT			MATERIALS		
				Type	No.	Hours	Type	Unit	Quantity
①	A. Construct Turnout: 1. Light Clearing & grubbing. 2. Spread Gravel.	1 Squad	2 hr.	Squad Pioneer Tool Set	1	2 hr.	bank gravel (on site)	cu. yd.	3
	B. Set up Equipment.	WP Team	½ hr.	Mobile Water Purification Unit, 1500 GPH	1				

RECONNAISSANCE REPORT ON OTHER SIDE

Figure 5. Engineer reconnaissance report form—back of form.

WATER RECONNAISSANCE REPORT (TM 5-700)		DATE 8 Sep 60	PAGE 1 OF 3 PAGES
TITLE NUMBER	REPORT NUMBER 1	REPORTED BY (Name - Grade - Organization) Walter J. Newman, Sfc 86th Engrs Co	
FORWARDED TO S-4, 37th Gp			

1. LOCATION OF WATER SOURCE

MAP	COORDINATES
FT Belvoir & Vicinity, 1:25000	516723

2. TYPE OF SOURCE (Check one) ☐ Other (specify)	LOCAL NAME OF SOURCE
☑ Stream ☐ Lake ☐ Pond ☐ Spring ☐ Well ☐ Reservoir	Accotink Creek

3. DATE AND HOUR INSPECTED	4. YIELD	
	IMMEDIATE (gpm)	ULTIMATE (gpm) (Give work estimate)
08 1400 60	12,500	17,000 108 Man hours

5. QUALITY

COLOR	ODOR	TASTE
Clear	None	Muddy
TURBIDITY (estimate)	**pH TEST**	**CHLORINE DEMAND TEST (ppm)**
Less than 50	7.5	3.5

POSSIBLE SOURCE OF POLLUTION
Algae

6. COMMUNICATIONS

DISTANCE TO CONSUMERS	ROADS	RAILROADS	BRIDGES
10 Mi	Good	None	None

7. SITE CONDITIONS (If municipal system, use Items 9 and 10)

SECURITY Overhead concealment good. Security against ground attack must be provided.

DRAINAGE
Good

BANKS (If surface source)
Stable & sloping — about 3' high

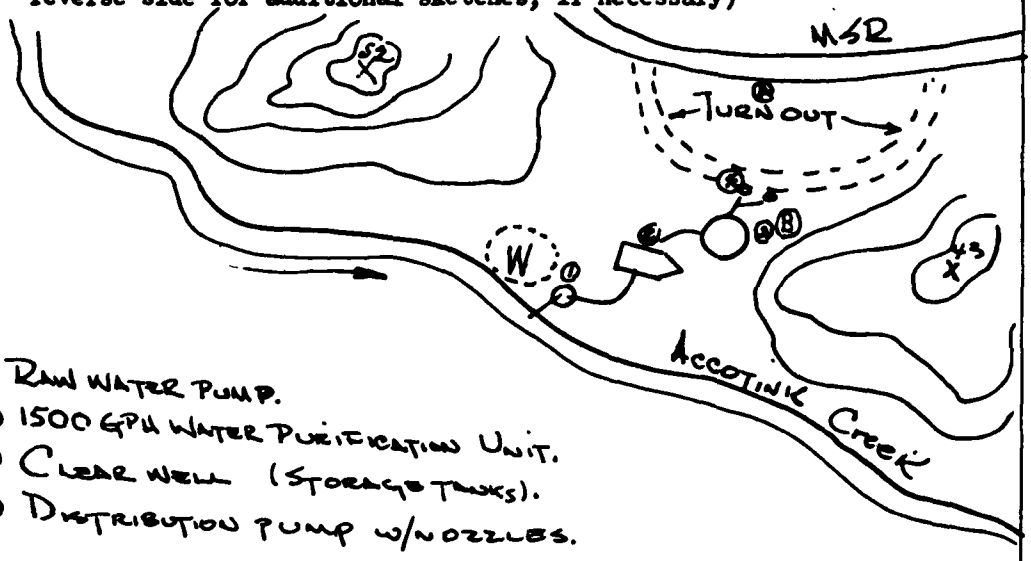
DISTRIBUTION FACILITIES (existing)
None

8. SKETCH OF AREA (Show road net and traffic circulation) (Use reverse side for additional sketches, if necessary)

See reverse side.

DA Form 1712-R, 1 Jun 61 Edition of 1 May 56 is obsolete.

9. **SKETCH OF WATER POINT** (Show proposed set up for immediate operation. If water point is a municipal system, include sketch of system) (Use reverse side for additional sketches, if necessary)

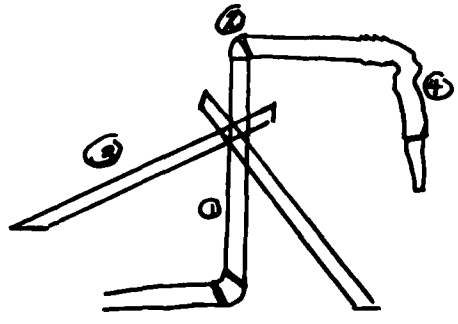


① RAW WATER PUMP.
② 1500 GPH WATER PURIFICATION UNIT.
③ CLEAR WELL (STORAGE TANKS).
④ DISTRIBUTION PUMP W/NOZZLES.

10. **DESCRIPTION AND SKETCH OF PROPOSED DEVELOPMENTS** (If municipal system, include survey) (Use reverse side for additional sketches, if necessary)

Ⓐ PROPOSED TURNOUT (APPROX. 75 METERS LONG)

Ⓑ STANDPIPES FOR DISTRIBUTION



NOTE: SEE MATERIALS LISTED IN ITEM 11.

11. WORK ESTIMATES			
FOR IMMEDIATE OPERATION			
TASK	**MAN-HOURS**	**EQUIPMENT**	**MATERIAL**
① Construct Turnout 1- Light clearing & grubbing 2- Haul & spread gravel.	96	① 5 sq ft pioneer set. ② D-7 (Dozer)	40 cubic yards of gravel
② Setup equipment.	6	1500GPH Mobile water purification unit.	None
FOR DEVELOPMENTS			
TASK	**MAN-HOURS**	**EQUIPMENT**	**MATERIAL**
③ Stand-pipes	6	① Pipe wrenches ② Hammer ③ Saw	① 2" pipe — 1 pc. 8' long and 1 pc 2' long ② 2" 90° Elbow, 2 ea. ③ 2"x4" lumber 6' long - 2 ea ④ 1 length of 2" canvas hose with distribution noggle. Note: Material for 1 ea stand pipe.
TYPE OR PRINTED NAME AND GRADE Walter J Newman SFC		SIGNATURE Walter J Newman	

APPENDIX III

WATER REQUIREMENTS; WATER SUPPLY AND DESTRIBUTION EQUIPMENT

The following tables were taken from reference [18], Appendix B, pages 141, 142, 143, 144, and 145.

Table 1. Daily Water Requirements

1	2	3		4
Unit consumer	Conditions of use	Gal per unit Consumer per day		Remarks
		Temperate/cold climate	Desert/jungle	
Man	In combat:			
	Minimum	½–1	[1]2–3	For eating and drinking only, periods not to exceed 3 days.
		2	[1]3–4	When field rations are used.
	Normal	3	[2]6	Drinking plus small amount for cooking or personal hygiene.
	March or bivouac	2	[2]5	Minimum for all purposes.
	Temporary camp	5		Desirable for all purposes (does not include bathing).
	Temporary camp with bathing facilities	15		Includes allowance for waterborne sewage system.
	Semipermanent camp	30–60		
	Permanent camp	60–100		
Vehicle	Level and rolling country.	1/8–1/2		Depending on size of vehicle.
	Mountainous country.	½–1		Depending on size of vehicle.
Locomotive (steam)	Standard military	Variable		150 gallons per train-mile.
	Commercial	Variable		200 gallons per train-mile.
Hospital	Drinking and cooking	10 per bed		Minimum; does not include bathing or water for flushing.
	Water waterborne sewage.	50 per bed		Includes water for medical personnel.
Impregnating plant, clothing, M2A1.	Maximum impregnating capacity.	2,400		Aqueous process. Includes 2,000 gallons for plant operations and 400 gallons for washing and cleaning purposes.
QM bakery company (mobile).	Two 10-hour shifts	2,600		Water for making bread and cleaning baking utensils.
QM laundry company.	Two 10-hour shifts	64,000 (4,000 per unit.)		

[1] For unacclimatized personnel or for all personnel when dry bulb readings exceed 105°F. in the jungle.
[2] Maximum consumption factor is dependent upon work performed, solar radiation, and other environmental stresses.

Table 1. Daily Water Requirements—Continued

1	2	3		4
Unit consumer	Conditions of use	Gal per unit Consumer per day		Remarks
		Temperate/cold climate	Desert/ jungle	
QM clothing exchange and bath company.	Two 10-hour shifts	360,000 (60,000 per unit.)		
Truck-mounted 400-gallon decontaminating apparatus.	Decontamination	4,000		Water obtained from natural source when available.
Chemical base laboratory, M2.	Normal laboratory work.	300		

Table 2. Quality and Quantity of Water Needed by Construction Equipment

Equipment	Size	Quantity	Purity of Water
Rock Crusher	75–T	22,500–45,000 GPH*	No special purification. Sea water usable.
Rock Crusher	225–T	100,000–200,000 GPH*	
Concrete Mixer	16S	700 GPH	Potable; minimum of organic matter. Acid, alkali free. Sea water may be used, but decreases concrete strength by 20%. Extra cement may be used to offset this effect.
Concrete Paver	34E	3,500 GPH	
Central Mix Plant	112S	4,800 GPH	
Asphalt Plant		1,000 GPH	Alkali free, low sulfates.
Steam Jenny		850 GPH	Potable; low calcium and magnesium.
Steam Boiler (No condensate return).	200 hp	2,000 GPD	
Three Car Heater (for asphalt plants no condensate return).	52 hp	200 GPH	
Water Distributor	1,000 gal	1,000 gal/100 yds of 8' road	No special purification. Salt water acceptable.

* Gallon per hour (GPH) requirement for rock crushers is 8 to 10 times the number of cubic yds/hr. This is dependent upon type of aggregate and amount of sand.

Table 5. Water Supply and Distribution Equipment

a. Water Equipment Issued to Engineer Units.

1	2	3	4	5	6	7	8	9	10	11	12
Unit	Number of sets [1]	Type purif unit: fresh water (GPH)	Generator (kw)	Chemicals required (lb/hr)[2]	Equipment in each set		Pump discharge (GPM/SET) [3]		Total Storage Capacity (gal)	Max production (GPH)	Water transport equipment
					Tanks						
					Number	Capacity (gal)	Distrib	Purif			
Airmobile div engr bn	5	600(420)[4]	3	1.0	3	1,500	65	10	6,000	2,400	
Abn div engr bn	5	600(420)[4]	3	1.0	3	1,500	65	10	6,000	2,400	
Armd, inf, & mech div engr bns	5	1,500	10	2.4	3	4,500	125	25	22,500	7,500	
Engr combat bn, army	5	1,500	10	2.4	3	4,500	125	25	18,000	6,000	
Engr const bn	2	1,500	10	2.4	3	4,500	125	25	9,000	3,000	
Engr co, separate bde, armd, inf, or mech	2	1,500	10	2.4	3	4,500	125	25	9,000	3,000	
Engr co, separate bde, airborne	2	600(420)[4]	3	1.0	3	1,500	65	10	6,000	2,400	
Engr WS co	9	3,000 (mobile)	10	4.7	3	9,000	125	50	81,000	27,000	9–2,000 gal
Water purif team (GF)	1	3,000 (base)	15	4.7	3	9,000	125	50	9,000	3,000	
Water purif team (GG)	4	3,000 (base)	15	4.7	3	9,000	125	50	36,000	12,000	
Water transport team (GH)											3–2,000 gal
Well drilling team (GE)	2	well drilling sets.									

[1] Each set can equip one water point.
[2] Each set has chemical supplies for 600 hours of operation: 1/16 of supplies transported with each mobile unit.
[3] One pump at steady purification rate: others at full rated capacity for distribution (intermittent operation).
[4] As discussed in paragraph 50 this unit is subject to change.

Table 3. Water Supply and Distribution Equipment—Continued

b. Distillation Units.

1	2	3	4	5	6	7	8	9	10	11	12
1 Type	Distillate capacity		Economy lb	Fuel required		Raw water required (GPH)	Mounting	Weight (lb)	Dimensions		
	GPH	GPD [1]	distilled per lb of fuel	Type	GPH				Length	Width	Height
Thermo-compression	150	3,000	150	Gasoline	1.5	300	Trailer or skid.	5,700 3,200	14'–5" 8'–11"	8'–0" 4'–7"	8'–0" 6'–3"

[1] The distillate capacity in GPD is based on a 20-hour operational day.

Table 3. Water Supply and Distribution Equipment—Continued

c. Water Distribution Equipment.

1	2
Equipment	Capacity
Trailer, cargo, 1½-ton, 2-wheel	60 cans filled
Trailer, tank, water, 2-wheel	400 gal
Truck, cargo, 2½-ton, 6 x 6, LWB	100 cans filled
Truck, tank, water, 2½-ton, 6 x 6	1,000 gal
Strlr, tank, water, w2½-ton trk track or	2,000 gal
Unit kitchen	5-gal cans, wt 50 lb (filled).

d. Capacities of Other Water Supply Equipment.

1	2
Equipment	Capacity
Deep well pumps:	
Helical rotor-type	60 GPM against 250-ft head.
Turbine type, 6-inch	200 GPM against 200-ft head.
Percussion well drilling machine	6- to 8-inch well, 1,000 to 500 ft.
Rotary well drilling machine	4- to 6-inch well, 350 to 150 ft.
Rotary well drilling machine	4- to 6-inch well, 1,500 to 1,000 ft.
Surface pumps, centrifugal type gasoline engine drive:	
2-inch suction and discharge	125 GPM at 50-ft head
1½-inch suction and discharge	65 GPM at 50-ft head

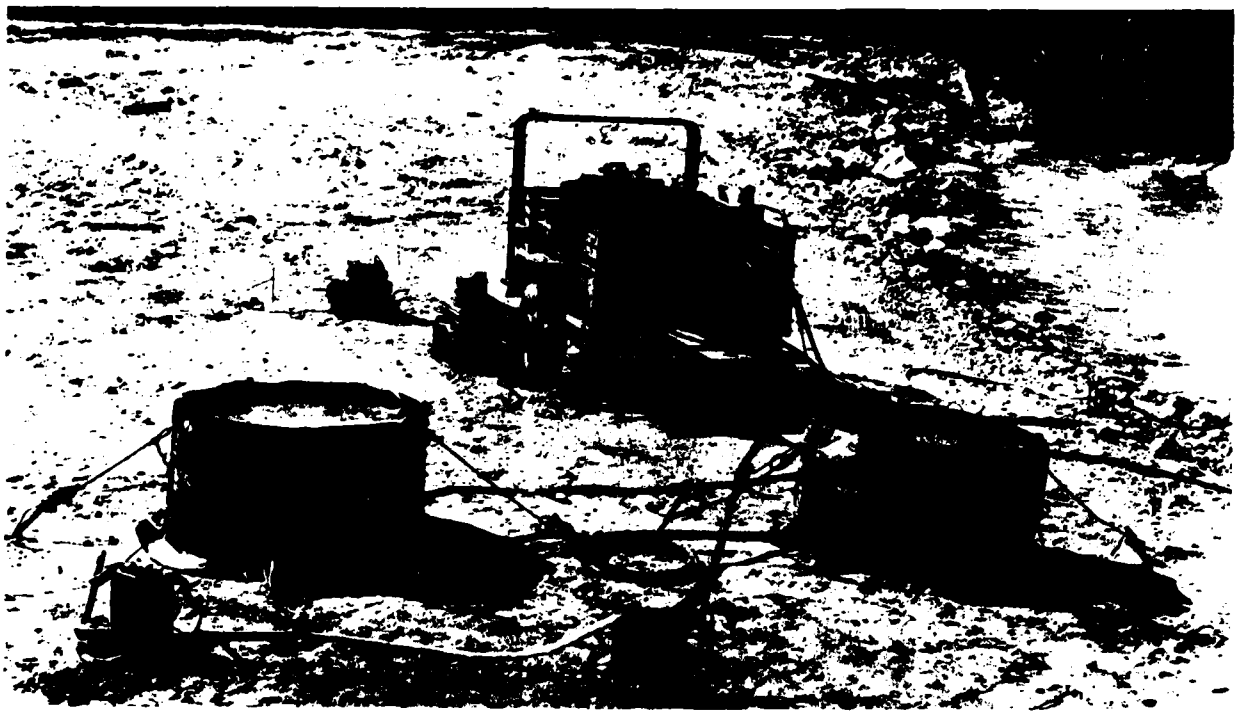


Figure 45. 600-gph W. P. U. setup for operation.

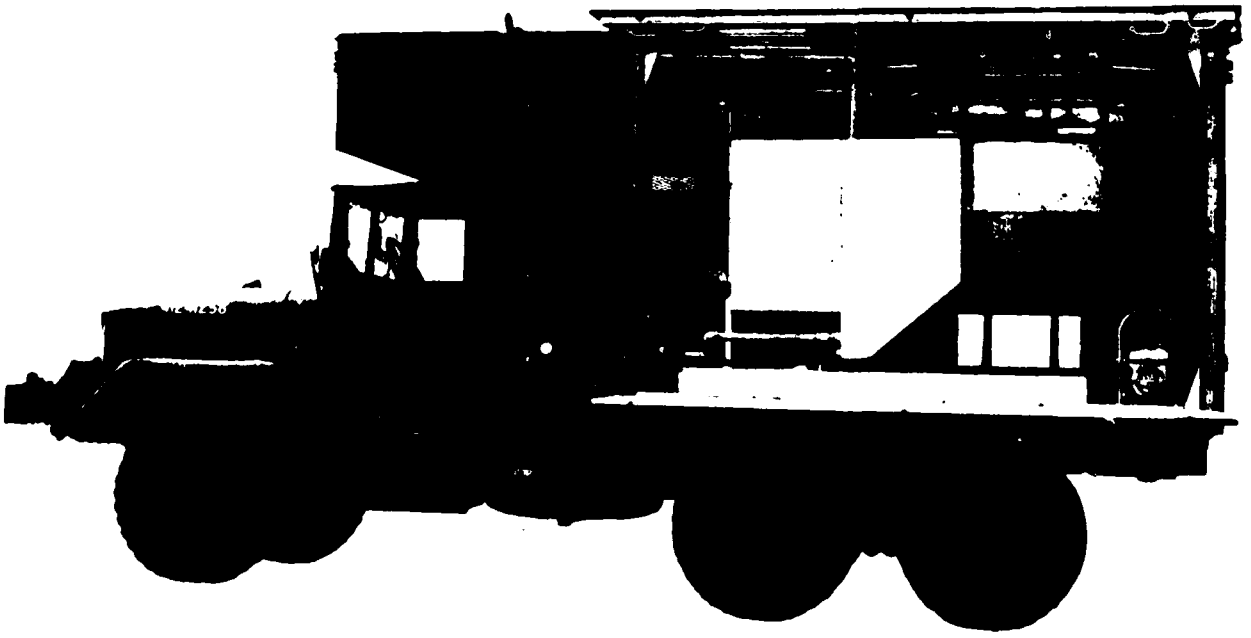


Figure 47. W. P. U. van type body mounted 1,500-gph.

APPENDIX IV

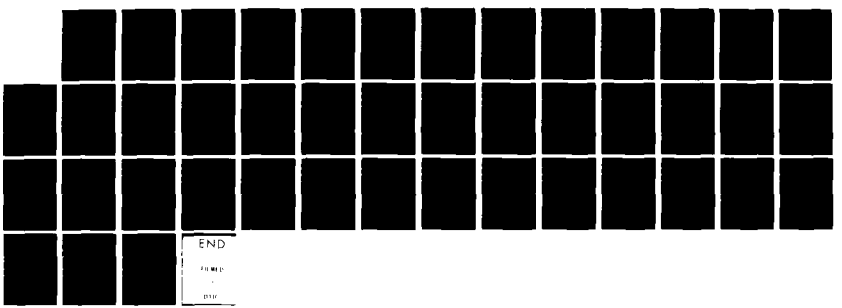
PROGRAM NTRACE

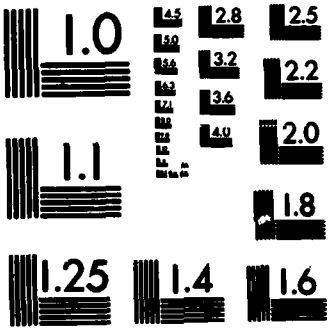
Program NTRACE accepts all input data for this prototype DSS. It was written by Monty J. Anderson, CPT., EN, at Georgia Institute of Technology, Atlanta, Georgia.

```
10 '$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
20 '$PROGRAM-NTRACE 'PREPARES DATA INPUT FOR PROGRAM COMPUTE'
30 '$A PROTOTYPE DECISION SUPPORT SYSTEM FOR WAREHOUSE LOCATION  ON A ROAD NETWORK.
40 '$FOR DOCUMENTATION SEE MASTERS THESIS BY MONTY J. ANDERSON, CPT. USA
50 '$GEORGIA INSTITUTE OF TECH., PROF DONOVAN YOUNG, CHAIRMAN
60 HT=0:TR=0
70 IF B1 AND B2 THEN B1=0:B2=0:GOSUB 860:GOTO 4300      'CHANGE SUPPLY/DEMAND IF CHAINED FROM COMPUTE
80 IF B1 THEN GOSUB 860:GOTO 4850                       'MINOR RESTART IF CHAINED FROM COMPUTE
90 IF B2 THEN GOSUB 860:GOTO 4710                       'MAJOR RESTART IF CHAINED FROM COMPUTE
100 CLEAR:DEFINT A,I,J,N,Q,S,Z                           'INITIALIZE VARIABLES IF NOT CHAINED FROM COMPUTE
110 PRINT CHR$(12);"~X2,~Y2,~C6~Q5";
120 PRINT"ENTER PROBLEM NAME"
130 LINE INPUT"(For Disk Storage of Data):  ~C5";A$
140 IF LEN(A$)=0 THEN 100                                 'REPROMPT IF NULL ENTRY
150 DIM NN(30)                                           'GENERAL PURPOSE STORAGE ARRAY
160 'NN(0)=ACTUAL # OF NODES IN PROBLEM;NN(16)=MAXIMUM # OF NODES ALLOWED IN PROBLEM; NN(13)=FLAG FOR NEW COST MATRIX
170 'NN(1),NN(4),NN(2),NN(5)=LOWER LEFT AND UPPER RIGHT X&Y BITPAD SCALING POINT COORD RESPECTIVELY
180 'NN(3),NN(6)=COMPUTED X&Y SCALING CONSTANTS FROM ABOVE VALUES
190 'NN(7),NN(8)=# OF SOURCES AND SINKS IN PROBLEM;NN(9),NN(10),NN(15)=CONSTANT VALUESFROM SUBROUTINE 2600
200 DIM DZ(1,1),NX(1),NY(1),NS(1),NT(1),AL(1)            'DIM ARRAYS FOR NETWORK DATA
210 DIM SR(1),SK(1),IS(1),Q(1)                           'ARRAYS FOR SUPPLY/DEMAND
220 DIM SD(1),SP(1),N1(1),IC(1,1)                        'ARRAYS FOR SHORTEST PATH
230 DIM ID(1),NF(1),ND(1),NR(1),NU(1),IU(1),ZP(1)        'ARRAYS FOR TRANSP ALGORITHM
240 DIM NP(1),X(1),Y(1)                                  'ARRAYS FOR GRAPHING
250 PRINT CHR$(12);
260 PRINT"IS THERE DATA PRESENTLY STORED UNDER NAME:                  ~C4";A$
270 LINE INPUT"~C6             Yes=Y or No=N  ~C5";Z$
280 IF LEFT$(Z$,1)="Y" THEN GOSUB 2700:GOSUB 860:GOTO 1000 'RETRIEVE STORED DATA
290 PRINT CHR$(12);:GOSUB 2100                            'INPUT CONSTANT VALUES FOR NEW PROBLEM
300 PRINT CHR$(27);"R1C";CHR$(27);"OE5";CHR$(27);"IE5";'ESTABLISH COMMUNICATIONS WITH BITPAD
310 PRINT#4; "H"
320 PRINT CHR$(12);"~C6~X2,~Y2,YOU MAY NOW ENTER A NETWORK FOR STORAGE IN DISK FILE:~C4  ";A$
330 PRINT CHR$(10);"~C7HIT ~C5CARRIAGE RETURN~C7 AND"
340 PRINT" FOLLOW TRACING INSTRUCTIONS"
350 PRINT CHR$(10);"~C1DO YOU WANT INSTRUCTIONS: ~C5~1YES=Y OR NO=N~2~C1~J ";
360 LINE INPUT S$:IF LEFT$(S$,1)<>"Y" THEN 480        'SKIP ALL INSTRUCTIONS IF S$<>"Y"
370 PRINT CHR$(12);"~=~C4~U001300";
380 PRINT"YOU SHOULD NOW PREPARE TO ENTER THE DESIRED NETWORK.";
390 PRINT"THE AREA ON THE MAP OF CONCERN   MUST BE NO MORE THAN 10 INCHES BY 10 ";
400 PRINT"INCHES.  CENTER THE IDENTIFIED AREA ON THE    BITPAD AND SECURE IT IN PLACE ";
410 PRINT"WITH TAPE.  IDENTIFY A POINT IN BOTH THE LOWER LEFT    CORNER AND UPPER ";
420 PRINT"RIGHT CORNER THAT IS NO MORE THAN 1/4 INCH OUTSIDE BOTH THE X AND Y AXIS ";
430 PRINT"BOUNDRIES OF THE IDENTIFIED AREA. "
440 PRINT CHR$(10);"~X002~Y002~C6THESE TWO POINTS WILL BE USED BY ";
450 PRINT"YOU TO   SCALE THE SIZE OF THE IDENTIFIED ";
460 PRINT"AREA TO  THE FULL SIZE OF THE SCREEN."
470 LINE INPUT"~C5HIT RETURN WHEN YOU ARE READY TO BEGIN.~C7~G+0,0,511,511";Z$
480 PRINT CHR$(12);"~=~U1,100~C4~K";
490 PRINT "TOUCH LOWER LEFT SCALE POINT WITH STYLUS OR DEPRESS ANY BUTTON ON THE CURSOR"
500 PRINT "AFTER IT IS CENTERED ON THE SCALE POINT.  LISTEN FOR A BELL.~U001255~C6"
```

```
510 PRINT 'IF YOU DO NOT HEAR A BELL THEN YOU ARE OUTSIDE OF THE SENSITIVE AREA '
520 PRINT 'ON THE BITPAD.  DECREASE THE SIZE OF THE AREA TO BE TRACED.'
530 INPUT#4,X,Y,F$:IF F$='1' OR F$='3' OR F$='4' OR F$='8' THEN NN(1)=X:NN(4)=Y ELSE 530
540 PRINT CHR$(12);'~U001500~C4';CHR$(7);
550 PRINT 'TOUCH UPPER RIGHT SCALE POINT WITH STYLUS OR DEPRESS ANY BUTTON ON THE CURSOR'
560 PRINT 'AFTER IT IS CENTERED ON THE SCALE POINT.  LISTEN FOR A BELL.~U001255~C6'
570 PRINT 'IF YOU SO NOT HEAR A BELL THEN YOU ARE OUTSIDE OF THE SENSITIVE AREA ON ' _
580 PRINT 'THE BITPAD.  DECREASE THE SIZE OF THE AREA TO BE TRACED.';
590 F$='0':PRINT'~7020'
600 INPUT#4,X,Y,F$:IF F$='1' OR F$='3' OR F$='4' OR F$='8' THEN NN(2)=X:NN(5)=Y ELSE 600
610 NN(3)=(NN(2)-NN(1))/512:NN(6)=(NN(5)-NN(4))/412
615 TR=1:ON ERROR#2 GOTO 2000:OUT&H90,0
620 PRINT CHR$(12);'~C4~U001450';CHR$(7);:IF LEFT$(S$,1)<>'Y' THEN HT=5:GOSUB 850:GOTO 4100
630 PRINT'YOU HAVE FINISHED THE SCALING OF THE MAP.  YOU ARE NOW READY TO INPUT THE'
640 PRINT 'LOCATIONS OF~C6 ALL~C4 ROAD INTERSECTIONS~C6 AND ROAD END POINTS~C4 THAT EITHER:  '
650 PRINT CHR$(10);'1)  LEAVE THE EDGE OF THE AREA THAT WAS SCALED EARLIER.'
660 PRINT CHR$(10);'2)  TERMINATE AT ANY POINT INSIDE OF THE SCALED AREA.'
670 PRINT CHR$(10);'TO DESIGNATE A POINT AS A NODE YOU NEED ONLY';
680 PRINT 'POSITION THE CURSOR OVER IT AND PRESS THE ~C1BLUE~C4 BUTTON.  ';
690 PRINT 'A BELL WILL SOUND INDICATING THAT THE   NODE WAS ACCEPTED AND A~C1 BLUE~C4  ';
700 PRINT 'CIRCLE WILL APPEAR ON THE SCREEN.  ~C6TAKE CARE TO ENTER AS MANY NODES ';
710 PRINT 'AS YOU CAN IDENTIFY.  ALL CONNECTING ROADS ';
720 PRINT 'MUST START AND END AT A NODE.'
730 LINE INPUT'~C5~X003~Y003HIT RETURN TO CONTINUE.';Z$'PLAIN WAIT FOR CARRIAGE RETURN
740 HT=5:GOSUB 850:GOTO 4100                          'BRANCH TO DIGITIZER ROUTINE
840 '$$$THIS SUBROUTINE PRINTS THE MENU AND SETS INITIAL WINDOW CONDITIONS
850 PRINT '~=';CHR$(12);
860 PRINT CHR$(27);'0A1~=~W300,1005110,~R~Q5';CHR$(12);
870 PRINT CHR$(27);'0A0~=~K~C3~F~B';
880 PRINT '$25,50,10,07550,10,12550,10,17550,10,';
890 PRINT '22550,10,27550,10,~L';CHR$(21);
900 PRINT '~U016080ADD~U1,030NODE/ARC';
910 PRINT '~U054080STOP OR~U061030SAVE~U061020DATA';
920 PRINT '~U107080CHANGE~U107030SUPPLY/~U107020DEMAND';
930 PRINT '~U154080COMPUTE~U163030FLOW';
940 PRINT '~U204080DISPLAY~U201030ANALYSIS';
950 PRINT '~U254080RESTART';
960 RETURN
1000 '$$$THIS IS THE INFINATE LOOP SECTION TO WAIT FOR A LIGHT PEN HIT
1010 TR=1:ON ERROR#2 GOTO 2000:OUT&H90,0              'ACTIVATE LIGHT PEN INTERRUPT
1020 PRINT CHR$(27)'0A1~C6LIGHT PEN ACTIVATED~C7~K'
1030 PRINT CHR$(10);CHR$(27);'0A0~K';
1040 GOTO 1040
1100 '$$$THIS SECTION CONTROLS THE INPUT SIGNAL FROM THE 4 BUTTON CURSOR WITH DIGITIZER PAD
1110 ON ERROR#0 GOTO 0:ON ERROR#2 GOTO 2000:OUT&H90,0
1120 PRINT#4,'J':PRINT CHR$(27);'0A0';                'SET BITPAD A 10 COORD/SEC
1130 'RECEIVE COORD PLUS FLAG FROM BITPAD; IGNOR IF F$ IS NOT '4' OR '8' FOR BLUE AND GREEN BUTTON RESPECTIVELY
1140 INPUT#4,X,Y,F$:IF F$='4' OR F$='8' THEN 1150 ELSE 1140
1150 IF X<=0 OR Y<=0 THEN 1140                        'REJECT INPUT IF ZERO
1160 XP=FNPX(X):YP=FNPY(Y)                            'SCALE BITPAD COORD TO SCREEN
```

AD-A122 192 A PROTOTYPE DECISION SUPPORT SYSTEM FOR THE LOCATION OF 2/2
MILITARY WATER POINTS(U) GEORGIA INST OF TECH ATLANTA
SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING
UNCLASSIFIED M J ANDERSON JUN 80 F/G 5/1 NL





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1170 IF XP<0 OR YP<0 OR XP>511 OR YP>511 THEN 1140      'REJECT COORD IF OUTSIDE SCALED AREA
1180 IF F$="4" THEN GOSUB 1400                         'IF BLUE BUTTON THEN ESTABLISH A NODE
1190 IF F$="8" THEN GOSUB 1500                         'IF GREEN BUTTON THEN DRAW AN ARC
1200 GOTO 1140
1400 '$$$THIS SUBROUTINE INCREMENTS THE NODE COUNTER
1410 SH=5:GOSUB 1900:IF SH<>5 THEN 1440                'IGNOR NODE REQUEST IF DISTANCE IS < 5 DOTS
1420 PRINT CHR$(7);:N=N+1:CL=N:NN(0)=N
1430 NX(N)=XP:NY(N)=YP:PRINT "^C3";:GOSUB 1900         'RECORD NODE COORD; PLOT ON SCREEN
1440 RETURN
1500 '$$$THIS SUBROUTINE DRAWS THE ARCS BETWEEN THE NODES
1510 PRINT#4; "I"
1520 SH=25:GOSUB 1900                                  'FIND DISTANCE TO CLOSEST NODE
1530 IF SH=25 THEN GOSUB 1400:SH=0:CL=N ELSE PRINT CHR$(7);'ESTABLISH NODE IF DISTANCE > 25 DOTS
1540 PRINT "^1^K^F^C2^8";
1550 PLOT NX(CL),NY(CL),2                              'PLOT BLINKING GREEN CIRCLE
1560 PRINT "^2^L(";:PLOT NX(CL),NY(CL)                 'PLOT CONCATENATED VECTOR
1570 PLOT XP,YP:XO=XP:YO=YP:S=CL                       'REMEMBER OLD VALUES
1580 INPUT#4;X,Y,F$
1590 XP=FNPX(X):YP=FNPY(Y)
1600 DI=ABS(XP-XO)+ABS(YP-YO)
1610 IF DI>100 THEN 1580
1620 PLOT XP,YP
1630 IF F$<>"8" THEN 1660
1640 XO=XP:YO=YP:SU=SU+DI                              'SUM DISTANCE FROM LAST COORD
1650 GOTO 1580
1660 SH=25:GOSUB 1900
1670 IF SH=25 THEN GOSUB 1400:SH=0:CL=N
1680 SU=SU+SH:PLOT NX(CL),NY(CL)
1690 PRINT"^F^C3";:PLOT NX(S),NY(S),2
1700 PRINT"^L";CHR$(21);
1710 DX(S,CL)=SU:DX(CL,S)=SU:SU=0                      'RECORD TWOWAY ARC
1720 RETURN
1800 '$$$THIS SUBROUTINE FINDS THE CLOSEST NODE TO THE LIGHT PEN HIT
1810 FOR J=1 TO NN(0)
1820     DI=ABS(NX(J)-XP)+ABS(NY(J)-YP)
1830     IF DI<SH THEN SH=DI:CL=J
1840 NEXT
1850 RETURN
1900 '$$$THIS SUBROUTINE PLOTS THE NODE NUMBER AND A CIRCLE AT THE NODES COORD
1910 PRINT "^U";:PLOT NX(CL),NY(CL)
1920 PRINT CHR$(21);
1930 IF CL<10 THEN PRINT USING "#";CL; ELSE PRINT USING "##";CL;
1940 PRINT "^K^F^8";:PLOT NX(CL),NY(CL),2
1950 RETURN
2000 '$$$THIS SECTION CONTROLS THE BRANCHING TO THE APPROPRIATE SECTION AFTER A LIGHT PEN HIT
2005 IF ERR=24 THEN 2010 ELSE ON ERROR#0 GOTO 0
2010 IF HT=0 THEN 2080                                 'IGNOR ALL LIGHT PEN HITS
2020 XP=CURSX(4):YP=CURSY(4)                           'RECEIVE LIGHT PEN HIT COORD
2030 ON HT GOTO 2040,3335,3835,3000,4100,4165          'IF HT<>1 THEN BRANCH TO APPROPRIATE SECTION
2040 XO=25:FOR I=1 TO 6                                'SEARCH THROUGH MENU FOR CLOSEST POINT
```

```
2050 DI=ABS(XP-XO)+ABS(YP-SO)
2060 IF DI<20 THEN PRINT CHR$(7);:ON I GOTO 4100,4200,4300,4400,4500,4600
2070 XO=XO+50:NEXT
2080 OUT1,H90,0:RESUME 1020
2100 '$$$THIS SECTION INPUTS CONSTANT VALUES FOR CALCULATION OF CAPACITIES & DEMANDS
2110 PRINT"^C6THE MAXIMUM NUMBER OF NODES MEMORY WILL   ALLOW IS 60."
2120 PRINT"^C3HOW MANY NODES WILL BE IN PROBLEM^C4 ";A$;"^C5^J";:MA=0:INPUT MA
2130 IF MA<1 OR MA>60 THEN 2110 ELSE NN(16)=MA
2140 PRINT CHR$(12);"^X1,^Y1,^C6YOU MUST NOW ENTER THE INITIAL DATA TO BE USED "
2150 PRINT"AS CONSTANT VALUES IN ALL SUBSEQUENT CALCULATIONS FOR PROBLEM!  ^C4";A$
2160 PRINT"^C6THE ONLY WAY TO CHANGE THE VALUES IS TO DO A^C7 ''^C4MINOR RESTART^C7'':PRINT
2170 PRINT"^C7WHAT IS THE WATER CONSUMPTION PER MAN FROM"
2180 NN(9)=0:INPUT"^C2ARMY^C7 TM 5-700, APPENDIX B, TABLE 1, PAGE 141^C5^J ";NN(9)
2190 IF NN(9)<=0 THEN 2170
2200 PRINT:PRINT"^C3TRUCK CAPACITY MUST BE IN TERMS OF ^C7GALLONS^C3."
2210 NN(10)=0:INPUT"HOW MUCH CAN YOUR TRUCK HAUL PER ROUND TRIP^C5  ";NN(10)
2220 IF NN(10)<=0 THEN 2200
2230 PRINT:PRINT"^C3WATER PURIFICATION EQUIPMENT SETS ARE^3"
2240 PRINT"AVAILABLE WITH DIFFERENT CAPACITIES.^3"
2250 PRINT"HOW MANY ^C7GALLONS PER HOUR^C3 WILL THE ONES ^3";
2260 NN(15)=0:INPUT"YOU WILL BE USING PROCUCE^C5";NN(15)
2270 IF NN(15)<=0 THEN 2230
2280 RETURN
2300 '$$$THIS SUBROUTINE ALLOWS FOR THE MANUAL CHANGING OF A SPECIFIC ARC LENGTH
2310 PRINT CHR$(12);"^2";
2320 LINE INPUT"^C7DO YOU WANT TO CHANGE A SPECIFIC   ARC LENGTH^C5^1?^2^C7  Yes=Y or No=N  ^J^C5";Z$
2330 IF LEFT$(Z$,1)<>"Y" THEN 2420 ELSE PRINT CHR$(12);
2340 S=0:INPUT"^C7ENTER THE START NODE #^C5";S:PRINT
2350 T=0:INPUT"^C7ENTER THE FINISH NODE #^C5";T
2360 IF S<1 OR S>NN(0) OR T<1 OR T>NN(0) THEN PRINT CHR$(12);"^C4^1ERROR ON INPUT^2^C7":GOTO 2300
2370 PRINT CHR$(12);"^C7THE PRESENT ^C4^1ONEWAY^2^C7 LENGTH OF THE   ARC FROM NODE#^C3";S;"^C7TO NODE#^C3";T;"^C7IS:  ^C4";DX(S,T)
2380 PRINT"^C6ENTER THE NEW DISTANCE."
2390 INPUT"^C7A Carriage Return ALONE RESULTS IN NO CHANGE.^1^C5";DX(S,T)
2400 NN(13)=0
2410 GOTO 2300
2420 RETURN
2500 '$$$THIS SUBROUTINE SAVES THE DATA INPUT
2510 PRINT "THIS IS THE FILE SAVE ROUTINE.":PRINT
2520 PRINT "TO SAVE DATA TYPE ^C5''^1STOP^2''^C7 THEN   \   ^C6RETURN.^C4^J  ";
2530 LINE INPUT Z$:IF Z$ <> "STOP" THEN 2520
2540 PRINT CHR$(27);"0A0^=^K^W0,1005110,";CHR$(12);
2550 '$$$THIS SUBSECTION SAVES DATA WITHOUT PROMPTING THE USER
2560 IF NN(7) THEN 2570 ELSE 2580
2570 DOS"ARYSAVE "+A$+"SR SR":DOS"ARYSAVE "+A$+"IS IS"
2580 IF NN(8) THEN 2590 ELSE 2600
2590 DOS"ARYSAVE "+A$+"SK SK"
2600 IF NN(7) OR NN(8) THEN DOS"ARYSAVE "+A$+"Q Q"
2610 NN(16)=MA:DOS"ARYSAVE "+A$+"NN NN"
2620 RETURN
2700 '$$$THIS SUBROUTINE RETRIEVES PREVIOUSLY SAVED DATA
```

```
2710 PRINT"^=^K"$CHR$(12)$
2720 DOS"REFRESH "+A$+$DOS"ARYLOAD "+A$+"NN NN"$KY=NN(13)$MA=NN(16)
2730 ERASE NX$DIM NX(MA)$DOS"ARYLOAD "+A$+"NX NX"
2740 ERASE NY$DIM NY(MA)$DOS"ARYLOAD "+A$+"NY NY"
2750 IF NN(7) THEN ERASE SR,IS$DIM SR(NN(7)+1),IS(NN(7)+1)$DOS"ARYLOAD "+A$+"SR SR"$DOS"ARYLOAD "+A$+"IS IS" ELSE 2770
2760 PRINT"^C6"$FOR I=1 TO NN(7)$CL=SR(I)$GOSUB 1900$NEXT
2770 IF NN(8) THEN ERASE SK$DIM SK(NN(8)+1)$DOS"ARYLOAD "+A$+"SK SK" ELSE 2790
2780 PRINT"^C1"$FOR J=1 TO NN(8)$CL=SK(J)$GOSUB 1900$NEXT
2790 ERASE Q$DIM Q(MA)
2800 IF NN(7) OR NN(8) THEN DOS"ARYLOAD "+A$+"Q Q"
2810 PRINT CHR$(21)$
2820 HT=1$RETURN
3000 '$$$THIS SUBROUTINE SPECIFIES THE NUMBER OF SOURCES AND THE NUMBER OF SINKS
3005 HT=4$PRINT CHR$(12)$
3010 INPUT "^C7HOW MANY WATER POINTS ARE THERE$    ^C5"$SR
3015 IF SR<=0 THEN 3010
3020 IF SR(1) THEN IF NN(7)=SR THEN 3040 ELSE 3025 ELSE 3035
3025 PRINT CHR$(27)$"OA0^C3"$$FOR I=1 TO NN(7)$CL=SR(I)$GOSUB 1900$Q(CL)=0$NEXT
3030 PRINT CHR$(27)$"OA1^C7"$
3035 NN(13)=0$NN(7)=SR$ERASE SR,IS$DIM SR(NN(7)+1),IS(NN(7)+1)
3040 INPUT "^C7HOW MANY UNITS ARE TO BE SUPPLIED$     ^C5"$SK
3045 IF SK<=0 THEN 3040
3050 IF SK(1) THEN IF NN(8)=SK THEN 3070 ELSE 3055 ELSE 3065
3055 PRINT CHR$(27)$"OA0^C3"$$FOR J=1 TO NN(8)$CL=SK(J)$GOSUB 1900$Q(CL)=0$NEXT
3060 PRINT CHR$(27)$"OA1^C7"$
3065 NN(13)=0$NN(8)=SK$ERASE SK$DIM SK(NN(8)+1)
3070 PRINT CHR$(12)$"YOUR PROBLEM "$A$$" NOW HAS^C4"$NN(7)$"^C7WATER    POINTS "$
3075 PRINT "AND^C4"$NN(8)$"^C7UNITS NEEDING WATER.  "
3080 LINE INPUT"DO YOU WANT TO CHANGE THESE NUMBERS Yes=Y or No=N^C5^1?^2^J "$Z$
3085 IF LEFT$(Z$,1)="Y" THEN 3000 ELSE PRINT CHR$(12)$
3090 LINE INPUT"^C7TO CHANGE THE ^C2COMBAT UNIT^C7 LOCATIONS OR STRENGTHS ^C5ENTER^C7 Yes=Y or No=N.   ^C5^1?^2^J"$Z$
3095 IF LEFT$(Z$,1)="Y" THEN GOSUB 3800$IF HT<>4 THEN 3040 ELSE PRINT"^C2ALL COMBAT UNITS HAVE BEEN ENTERED.^?030"
3100 PRINT CHR$(12)$
3105 LINE INPUT"^C7TO CHANGE THE ^C6WATER POINT^C7 LOCATIONS OR CAPACITIES ^C5ENTER^C7 Yes=Y or No=N  ^C5^1?^2^J"$Z$
3110 IF LEFT$(Z$,1)="Y" THEN GOSUB 3300$IF HT<>4 THEN 3010 ELSE PRINT"^C2ALL WATER POINTS HAVE BEEN ENTERED.^K^?030"
3115 Q(0)=0$Q(0)=IS(0)-SK(0)$IF Q(0)>0 AND SK(0)>0 THEN 3130 ELSE Q=ABS(Q(0))
3120 PRINT CHR$(12)$"^C4DEMAND EXCEEDS SUPPLY BY^C6^1"$Q$"^2^C4LOADS."
3125 PRINT "START OVER AND INCREASE SUPPLY OR  DECREASE DEMAND.^C7"$GOTO 3010
3130 HT=0$PRINT CHR$(12)$CHR$(7)$$RETURN
3300 '$$$THIS SUBROUTINE CONTROLS THE INPUT OF ALL SUPPLY POINT DATA
3305 S=0$IF SR(1) THEN S=NN(7)                    'INITIALIZE NODE POINTER
3310 PRINT "^K^C7USE THE LIGHT PEN TO INDICATE THE  WATER POINTS BY THEIR NODE NUMBER. "$
3315 PRINT "AFTER EACH HIT ENTER THAT SITE'S   MAXIMUM CAPACITY IN GALLONS PER    HOUR.  "$
3320 PRINT "TO ^C4STOP^C7 ENTER A MINUS '"^C5-^C7'   CAPACITY FOR A ^C6WATER POINT^C7.  "$
3325 PRINT "TO    "^C4DELETE^C7 A SITE ENTER '"^C50^C7'  CAPACITY."
3330 HT=2$OUT$H90,0$RESUME 1020                   'SET MENU SELECTOR & LIGHT PEN
3335 HT=0$SH=25$GOSUB 1800$IF SH=25 THEN 3330     'IGNOR HIT IF DISTNACE > 25 DOTS
3340 IF SK(0) THEN FOR J=1 TO NN(8)$IF CL<>SK(J) THEN NEXT ELSE 3330 'IGNOR NODE SELECTED IF ALREADY A COMBAT UNIT
3345 PRINT CHR$(7)$CHR$(27)$"OA0^C6^1"$$GOSUB 1900
3350 PRINT "^2"$CHR$(27)$"OA1"$
```

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3335 PRINT CHR$(12);"C7THE PRESENT CAPACITY OF "C4WATER SITE"C7 NODE#"C4";CL;"C7IS"C2";Q(CL);"C7TRUCK LOADS PER DAY."
3340 PRINT:INPUT"C5"1ENTER"2"C7 ITS NEW "C4GALLONS PER HOUR"C7     CAPACITY"C5"J";CP:PRINT CHR$(12);
3345 'CP=GALLONS PER HOUR CAPACITY
3370 'XB=CAPACITY PER 24 HOUR DAY; SI=INTEGER # OF WATER POINT EQUIPMENT SETS POSSIBLE
3375 '@=INTEGER # OF TRIPS AVAILABLE FOR RESUPPLY FROM THAT SITE
3380 XB=CP*24:SI=FIX(XB/(NN(15)*24))+1:Q=FIX(XB/NN(10)):S=S+1
3385 IF SI>1 THEN 3390 ELSE CS=Q:GOTO 3405              'ASSIGN MINIMUM OF ONE EQUIPMENT SET
3390 PRINT"C7HOW MANY EQUIPMENT SETS DO YOU WANT AT SITE"C4";CL;"C7.  MAXIMUM="C4";SI;:INPUT"C5";NE:PRINT
3395 IF NE>SI THEN 3390
3400 IF NE<SI THEN CS=FIX(NE*NN(15)*24/NN(10)) ELSE CS=Q
3408 PRINT CHR$(27);"OA0";:GOSUB 1900
3410 IF CP <0 THEN IF SR(0) THEN 3485 ELSE 3460         'EXIT SUBROUTINE IF NEGATIVE VALUE WAS ENTERED
3415 FOR I=1 TO NN(7):IF SR(I)<>CL THEN NEXT ELSE S=S-1:GOTO 3430
3420 IF S>NN(7) THEN PRINT CHR$(27);"OA0"C3";:GOSUB 1900:GOTO 3460
3425 SR(S)=CL:I=S
3430 IF CP=0 THEN PRINT"C3";:GOSUB 1900:KY=0 ELSE 3440
3435 S=S-1:IF Q(CL) THEN FOR J=I TO NN(7):SR(J)=SR(J+1):IS(J)=IS(J+1):NEXT:Q(CL)=0:GOTO 3330 ELSE 3330
3440 PRINT CHR$(27);"OA1"K"C4WATER SITE #"C4";CL;"C7CAN SUPPLY A TOTAL  OF"C4";CS;"C7LOADS PER DAY.":PRINT
3445 IF Q>CS THEN PRINT"C2IF"C4";SI;"C2EQUIPMENT SETS WERE USED IT   COULD PROVIDE"C4";Q;"C2LOADS PER DAY."C7"
3450 PRINT CHR$(27);"OA0";
3455 IS(I)=CS:Q(CL)=0:IF S=NN(7) THEN IF SR(0) THEN 3330 ELSE 3485 ELSE 3330
3460 PRINT CHR$(27);"OA1";CHR$(12);"JYOU HAVE ENTERED CAPACITIES FOR"C4";S;" "C7WATER POINTS.  ";
3465 PRINT "YOU MUST REDUCE THE NUMBER OF "C4WATER POINTS"C7 ";
3470 PRINT "OR DESIGNATE ADDITIONAL "C4WATER POINTS"C7."
3475 PRINT "DO YOU WANT TO REDUCE THE NUMBER OFWATER POINTS:  "1"C5YES=Y OR NO=N"C7"2  ";
3480 LINE INPUT Z$:IF LEFT$(Z$,1)="Y" THEN 3490 ELSE 3310
3485 IS(0)=0:SR(0)=0:FOR I=1 TO NN(7):SR(0)=SR(0)+Q(SR(I)):IS(0)=IS(0)+IS(I):NEXT:HT=4
3490 PRINT CHR$(7);CHR$(27);"OA1";CHR$(12);:RETURN
3500 '$$$THIS SUBROUTINE CONTROLS THE ENTERING OF ALL DEMAND POINT DATA
3805 S=0:IF SK(1) THEN S=NN(8)                          'INITIALIZE NODE POINTER
3810 PRINT CHR$(12);"K"C7NOW DESIGNATE THE COMBAT UNITS NODENUMBER WITH THE LIGHT PEN.  ";
3815 PRINT "AFTER  EACH HIT ENTER THAT UNIT'S TOTAL   PERSONNEL STRENGTH.  "
3820 PRINT "TO "C4STOP"C7 ENTER A MINUS '"C5-"C7' STRENGTH FOR A "C1COMBAT UNIT"C7.  ";
3825 PRINT "TO "C4DELETE"C7 A    "C1COMBAT UNIT"C7 ENTER '"C50"C7' STRENGTH."
3830 HT=3:OUT&H90,0:RESUME 1020
3835 HT=0:SH=25:GOSUB 1900:IF SH=25 THEN 3830
3840 IF SR(0) THEN FOR I=1 TO NN(7):IF CL<>SR(I) THEN NEXT ELSE 3830
3845 PRINT CHR$(7);CHR$(27);"OA0"C1"1";:GOSUB 1900
3850 PRINT "/"2";CHR$(27);"OA1";
3855 PRINT CHR$(12);"C7THE PRESENT STRENGTH OF THE "C2COMBAT UNIT"C7 AT NODE #"C4";CL;"C7REQUIRES"C4";Q(CL);"C7TRUCK LOADS PER D
3860 INPUT"C5"1ENTER"2"C7 ITS PRESENTLY ASSIGNED          "C4PERSONNEL STRENGTH"C5"J";NP
3865 Q=FIX(NP*NN(9)/NN(10))+1:S=S+1
3870 PRINT CHR$(27);"OA0";:GOSUB 1900
3875 IF NP<0 THEN IF SK(0) THEN 3935 ELSE 3910
3880 FOR I=1 TO NN(8):IF SK(I)<>CL THEN NEXT ELSE S=S-1:GOTO 3890
3885 SK(S)=CL
3890 IF NP=0 THEN PRINT"C3";:GOSUB 1900:KY=0 ELSE 3900
3895 IF Q(CL) THEN FOR J=I TO NN(8):SK(J)=SK(J+1):NEXT:Q(CL)=0:S=S-1:GOTO 3830 ELSE S=S-1:GOTO 3830
3900 PRINT CHR$(27);"OA1"K"C7UNIT AT NODE#"C4";CL;"C7MUST MAKE"C4";Q;"C7TRIPS PER DAY IF STRENGTH IS:"C4";NP CHR$(27)"OA0"
3905 Q(CL)=0:IF S=NN(8) THEN IF SK(0) THEN 3830 ELSE 3935 ELSE 3830
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```
3910 PRINT CHR$(27);"OA1";CHR$(12);"^J^C7YOU HAVE ENTERED CAPACITIES FOR^C4";S;"^C7UNITS.  ";
3915 PRINT "YOU MUST REDUCE THE NUMBER OF UNITS ";
3920 PRINT "OR ENTER ADDITIONAL PERSONNEL STRENGTHS.":PRINT
3925 PRINT "DO YOU WANT TO REDUCE THE NUMBER OF COMBAT UNITS?  ^1^C5YES=Y OR NO=N^C7^2  ";
3930 LINE INPUT Z$:IF LEFT$(Z$,1)="Y" THEN 3940 ELSE 3810
3935 SK(0)=0:FOR J=1 TO NN(8):SK(0)=SK(0)+Q(SK(J)):NEXT:HT=4
3940 PRINT CHR$(7);CHR$(27);"OA1";CHR$(12);:RETURN
4000 '$$$THIS SUBROUTINE COMPUTES THE LINKLIST DATA ARRAYS FROM THE D(I,J) MATRIX
4005 ERASE NS,NT,AL:DIM NS(MA+1),NT(S*MA),AL(S*MA)
4010 PRINT CHR$(27);"OA1";CHR$(12);
4015 PRINT "NOW COMPUTING LINKLIST DATA ARRAYS FOR PROBLEM:  ";A$
4020 PRINT"^C5^X002^Y002PLEASE WAIT^C7^X001^Y001^K"
4025 FOR I=1 TO N:FOR J=1 TO N
4030 IF DX(I,J)>0 THEN A=A+1:NT(A)=J:AL(A)=DX(I,J)
4035 NEXT J:NS(I+1)=A:NEXT I
4040 PRINT CHR$(12);CHR$(7);"PROBLEM ";A$;" HAS";NS(N+1);"ARCS."
4045 PRINT"^X2,^Y2,^C4NOW SAVING DATA^X1,^Y1,";
4050 DOS"ARYSAVE "+A$+"D DX":DOS"ARYSAVE "+A$+"NS NS"
4055 DOS"ARYSAVE "+A$+"NT NT":DOS"ARYSAVE "+A$+"AL AL"
4060 RETURN
4100 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE BITPAD DATA INPUT
4105 DEF FNPX(X)=FIX((X-NN(1))/NN(3)+.5)
4110 DEF FNPY(Y)=FIX((Y-NN(4))/NN(6)+.5)+100
4115 N=NN(0)
4120 PRINT CHR$(27);"OA1";CHR$(12);
4125 ERASE DX,NX,NY:DIM DX(MA,MA),NX(MA),NY(MA)
4130 IF NN(0) THEN PRINT"^X2,^Y2,^C4RETRIEVING DATA^X1,^Y1,^K":DOS"ARYLOAD "+A$+"D DX" ELSE ERASE Q:DIM Q(MA):GOTO 4155
4135 DOS"ARYLOAD "+A$+"NX NX":DOS"ARYLOAD "+A$+"NY NY"
4140 GOSUB 2300:PRINT CHR$(12);
4145 LINE INPUT"^C7DO YOU WANT TO USE THE DIGITIZER   PAD^C5^1?^2^C7  Yes=Y or No=N   ";Z$
4150 IF LEFT$(Z$,1)<>"Y" THEN 4180
4155 HT=4:PRINT CHR$(12);"^C2DIGITIZER ACTIVATED^K";CHR$(7);
4160 IF NN(0) THEN OUT&H90,0:RESUME 1100 ELSE GOTO 1100
4165 PRINTCHR$(27);"OA0^K^W0,1005110,";CHR$(12);
4170 DOS"PICTURE "+A$:NN(13)=0:DOS"ARYSAVE "+A$+"NN NN"
4175 DOS"ARYSAVE "+A$+"NX NX":DOS"ARYSAVE "+A$+"NY NY"
4180 GOSUB 860:GOSUB 4000:PRINT CHR$(12);
4185 HT=1:IF TR THEN OUT&H90,0:RESUME 1020 ELSE GOTO 1000
4200 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE STOPPING OF PROGRAM EXECUTION
4210 PRINT CHR$(27);"OA1^K";CHR$(12);
4220 GOSUB 2500:PRINT"^=";CHR$(12);:CLEAR:END
4230 OUT&H90,0:RESUME 1020
4300 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE INPUT OF DATA
4310 PRINT CHR$(27);"OA1";CHR$(12);:GOSUB 3000
4320 PRINT CHR$(12);"^X2,^Y2,^C6SAVING DATA^X1,^Y1,^K":GOSUB 2550
4330 PRINT CHR$(12);"^K^C2^1ALL DATA HAS NOW BEEN ENTERED.^2^C7"
4340 HT=1:IF TR THEN OUT&H90,0:RESUME 1020 ELSE TR=1:GOTO 1000
4400 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE CALCULATION OF FLOW
4410 PRINT CHR$(27);"OA1^K";CHR$(12);
4420 PRINT"^X2,^Y2,^C2PLEASE WAIT^X1,^Y1,";
```

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4440 IF NN(8) THEN 4470
4450 PRINT CHR$(12);"~C7YOU CAN NOT COMPUTE FLOW UNTIL THE NODES HAVE BEEN DESIGNATED.  YOU"
4455 PRINT"MUST ~C5CHANGE SUPPLY/DEMAND~C7 FIRST."
4460 GOTO 4490
4470 OUT &H90,0:RESUME 4480
4480 DOS"CHAIN COMPUTE"
4490 OUT&H90,0:RESUME 1020
4500 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE DISPLAY OF ANALYSIS
4510 PRINT CHR$(27);"0A1";CHR$(12);
4520 IF NN(7) AND NN(8) THEN 4560
4530 PRINT"~C6YOU CAN NOT DISPLAY AN ANALYSIS    UNTIL THE SUPPLY/DEMAND HAS BEEN   ENTERED."
4540 PRINT"YOU MUST ~C5CHANGE SUPPLY/DEMAND~C6 FIRST."
4550 GOTO 4580
4560 OUT &H90,0:RESUME 4570
4570 DOS"CHAIN COMPUTE"
4580 OUT&H90,0:RESUME 1020
4600 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE RESTART FUNCTION
4610 PRINT CHR$(27);"0A1";CHR$(12);
4620 PRINT"~C7@~C5A~C7=''~C6COMPLETE RESTART~C7.''"
4630 PRINT"~C7@~C5B~C7=''~C6MAJOR RESTART~C7.''"
4640 PRINT"~C7@~C5C~C7=''~C6MINOR RESTART~C7.''"
4650 PRINT"~C7@~C5D~C7=''~C2RETURN TO MENU CONTROL~C7.''"
4660 INPUT"~C5~1ENTER~2~C7 YOUR SELECTION~C5~J";Z:PRINT CHR$(12);
4670 IF Z<1 OR Z>3 THEN 4880
4680 ON Z GOTO 4690,4710,4850
4690 PRINT CHR$(12);"~C7A ~C4COMPLETE RESTART~C7 REQUIRES A NEW  ROAD NETWORK BE ~C6ENTERED~C7."
4700 GOSUB 25001:PRINT"~=";CHR$(12);CHR$(27);"E"
4710 PRINT CHR$(27);"0A1";CHR$(12);"~C7A MAJOR RESTART ASSIGNS A NEW      PROBLEM NAME TO THE EXISTING DATA."
4720 LINE INPUT"~1~C5MOUNT~C7~2 A ~C4NEW DISK~C7 ON DRIVE #2 AND    ~C5ENTER~C7 THE NEW PROBLEM NAME:~C5~J";B$
4730 IF LEN(B$)=0 THEN PRINT CHR$(12);:GOTO 4880 ELSE PRINT"~W0,1005110,~K";CHR$(12);
4740 B$=LEFT$(B$,5)
4750 DOS"REFRESH/1 "+A$:DOS"PICTURE/2 "+B$:ERASE DZ:DIM DZ(MA,MA)
4760 DOS"ARYLOAD/1 "+A$+"D DZ":DOS"ARYSAVE/2 "+B$+"D DZ":ERASE DZ:DIM DZ(1,1)
4770 NN(7)=0:NN(8)=0:NN(13)=0:GOSUB 2140:DOS"ARYSAVE/2 "+B$+"NN NN"
4780 ERASE NS,NT,AL:DIM NS(MA+1),NT(5*MA),AL(5*MA):DOS"ARYLOAD/1 "+A$+"NS NS"
4790 DOS"ARYSAVE/2 "+B$+"NS NS":DOS"ARYSAVE "+B$+"NX NX":DOS"ARYSAVE "+B$+"NY NY"
4800 DOS"ARYLOAD/1 "+A$+"NT NT":DOS"ARYLOAD "+A$+"AL AL":DOS"ARYSAVE/2 "+B$+"NT NT"
4810 DOS"ARYSAVE/2 "+B$+"AL AL":ERASE NS,NT,AL:DIM NS(1),NT(1),AL(1)
4820 PRINT CHR$(12);"~X2,~Y2,~C7ALL NETWORK DATA PREVIOUSLY STORED UNDER ~C4";A$
4830 PRINT"~C7IS NOW STORED UNDER NAME:  ~C5~1";B$:PRINT"~C4MOVE DISK FROM DRIVE#2 TO DRIVE#1."
4840 LINE INPUT"~2~C5ENTER~C7 Carriage Return TO CONTINUE.";Z$:A$=B$:GOSUB 860:GOTO 4880
4850 PRINT "~W0,1005110,";CHR$(12);"~C7A ~C2MINOR RESTART~C7 REQUIRES ONLY  CHANGES IN DATA OF PROBLEM NAME:~C6 ";A$
4860 GOSUB 2140:PRINT"~=~K";CHR$(12);NN(7)=0:NN(8)=0:NN(13)=0:DOS"REFRESH "+A$
4870 GOSUB 860:PRINT CHR$(27);"0A1";CHR$(12);
4880 NT=1:B1=0:B2=0:IF TR THEN OUT&H90,0:RESUME 1020 ELSE GOTO 1000
```

APPENDIX V

PROGRAM COMPUTE

Program COMPUTE performs all calculations and controls the display of the result of those calculations. It was written by Monty J. Anderson, CPT., EN, at Georgia Institute of Technology, Atlanta, Georgia.

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10 '$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
20 '$PROGRAM-COMPUTE 'WAREHOUSE LOCATION ON A ROAD NETWORK WITH INTERACTIVE GRAPHIC
30 '$SOLUTIONS.  FOR DOCUMENTATION SEE MASTERS THESIS BY MONTY J. ANDERSON, CPT. USA
40 '$GEORGIA INSTITUTE OF TECHNOLOGY, JUNE 1980.  PROF. DONOVAN YOUNG CHAIRMAN
50 DEF FNL(PO)=LOG(PO)/LOG(10) .                   'BASE TEN LOG FOR USE IN GRAPHING
60 DEF FNR(PO)=10^(INT(FNL(PO)+(FNL(PO)<0)))
70 DEF FND(PO)=INT(PO+.5+(X<0))                    'ROUND OFF TO NEAREST INTEGER FOR GRAPHING
80 HT=1:TR=0:GOTO 4400
850 '$$THIS SUBROUTINE SETS THE WINDOWS AND DRAWS THE MENU
860 PRINT CHR$(27);'OA1"="K"W300,1005110,"R"G5';CHR$(12);
870 PRINT CHR$(27);'OA0"="K"C3"F"G';
880 PRINT '$25,50,10,07550,10,12550,10,17550,10,';
890 PRINT '22550,10,27550,10,"L';CHR$(21);
900 PRINT '"U016080ADD"U1,030NODE/ARC';
910 PRINT '"U054080STOP OR"U061030SAVE"U061020DATA';
920 PRINT '"U107080CHANGE"U107030SUPPLY/"U107020DEMAND';
930 PRINT '"U154080COMPUTE"U163030FLOW';
940 PRINT '"U204080DISPLAY"U201030ANALYSIS';
950 PRINT '"U254080RESTART';
960 RETURN
1000 '$$THIS SECTION CONTAINS THE INFINATE LOOP TO WAIT FOR A LIGHT PEN HIT
1005 TR=1:ON ERROR$2 GOTO 2500:OUT$H90,0
1010 PRINT CHR$(27)'OA1"C4LIGHT PEN ACTIVATED"C7"K'
1020 PRINT CHR$(10);CHR$(27);'OA0"K';
1030 GOTO 1030
1800 '$$THIS SUBROUTINE FINDS THE CLOSEST NODE IN THE NETWORK
1810 FOR J=1 TO NN(0)
1820      DI=ABS(NX(J)-XP)+ABS(NY(J)-YP)
1830      IF DI<SH THEN SH=DI:CL=J
1840 NEXT
1850 RETURN
1900 '$$THIS SUBROUTINE PLOTS THE NODE NUMBER AND THE NODE CIRCLE POINT
1910 PRINT '"U';:PLOT NX(CL),NY(CL)
1920 PRINT CHR$(21);
1930 IF CL<10 THEN PRINT USING '#';CL; ELSE PRINT USING '##';CL;
1940 PRINT '"K"F"G8';:PLOT NX(CL),NY(CL),2
1950 RETURN
2000 '$$THIS SUBROUTINE RETRIEVES THE LINKLIST DATA ARRAYS WHEN NEEDED
2010 IF AL(1) THEN 2040
2020 ERASE NS,NT,AL:DIM NS(MA+1),NT(5*MA),AL(5*MA)
2030 DOS'ARYLOAD '+A$+'NS NS':DOS'ARYLOAD '+A$+'NT NT':DOS'ARYLOAD '+A$+'AL AL'
2040 RETURN
2500 '$$THIS SECTION CONTROLS THE BRANCHING OF ALL LIGHT PEN HITS
2505 IF ERR=24 THEN 2510 ELSE ON ERROR$0 GOTO 0
2510 IF HT=0 THEN 2580
2520 XP=CURSX(4):YP=CURSY(4)
2530 ON HT GOTO 2540,2580,2580,2580,4150
2540 XO=25:FOR I=1 TO 6
2550 DI=ABS(XP-XO)+ABS(YP-50)
2560 IF DI<20 THEN PRINT CHR$(7);:ON I GOTO 4100,4200,4300,4400,4500,4600
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2570 XO=XO+50:NEXT
2580 OUT&H90,0:RESUME 1010
3000 '$$$THIS SUBROUTINE SAVES THE SHORTEST PATH MATRIX FOR THE CURRENT DATA SET
3010 PRINT"^C4THIS IS THE FILE SAVE ROUTINE.":PRINT
3020 PRINT "^C7TO SAVE YOUR DATA^C6^1 Type^2^C7 ''^C5STOP^C7''    then ^C5Return.^J^C4":
3030 LINE INPUT Z$:IF Z$ <> "STOP" THEN 3070
3040 'THIS SECTION OF THE SUBROUTINE SAVES DATA WITHOUT PROMPTING THE USER
3050 DOS"ARYSAVE "+A$+"NN NN"
3060 DOS"ARYSAVE "+A$+"IC IC"
3070 RETURN
3200 '$$$THIS SUBROUTINE PLOTS THE NODES AFTER A REFRESH OF THE PICTURE
3210 PRINT "^C6":FOR I=1 TO NN(7):CL=SR(I):GOSUB 1900:NEXT
3220 PRINT "^C1":FOR J=1 TO NN(8):CL=SK(J):GOSUB 1900:NEXT
3230 HT=1:RETURN
4100 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE BITPAD DATA INPUT
4110 HT=5:PRINT CHR$(27)"0A1YOU HAVE HIT THE ADD MENU PT."
4120 PRINT"^C4TO ADD A NODE, ADD AN ARC OR MAKE"
4130 PRINT"CHANGES TO THE NETWORK OF PROBLEM^C2   "A$;"^C6 YOU MUST DO A ^C2MINOR RESTART^C6."
4140 LINE INPUT"^C4DO YOU WANT TO DO A ^C4MINOR RESTART^C7:    ^1^C6Yes=Y OR No=N^C5^2";Z$
4150 IF LEFT$(Z$,1)="Y" THEN B1=1:B2=0 ELSE PRINT CHR$(12);:GOTO 4180
4160 OUT &H90,0:RESUME 4170
4170 DOS"CHAIN NTRACE"
4180 HT=1:OUT&H90,0:RESUME 1010
4200 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE STOPPING OF PROGRAM EXECUTION
4210 PRINT CHR$(27);"0A1^K";CHR$(12);"YOU HAVE HIT THE STOP MENU PT."
4220 GOSUB 3000:PRINT"^=";CHR$(12);CHR$(27);"E";
4230 PRINT CHR$(12);CHR$(27);"0A0";
4240 OUT&H90,0:RESUME 1010
4300 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE INPUT OF DATA
4310 B1=1:B2=1
4320 OUT &H90,0:RESUME 4330
4330 DOS"CHAIN NTRACE"
4400 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE CALCULATION OF FLOW
4410 PRINT CHR$(27);"0A1";CHR$(12);
4440 IF NOT NN(13) THEN GOSUB 5400:PRINT "COST MATRIX IC(I,J) NOW COMPLETE.^T030"
4450 GOSUB 6000:PRINT CHR$(7);CHR$(12);
4460 IF TR THEN OUT&H90,0:RESUME 1010 ELSE 1000
4500 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE DISPLAY OF THE RESULTS
4504 A=0:DD=NN(7)+NN(8)+1:ERASE NP,X,Y:DIM NP(MA),X(MA),Y(MA)
4508 PRINT CHR$(27);"0A1";CHR$(12);
4520 PRINT CHR$(12);"^C7YOU HAVE A CHOICE OF 4 GRAPHS      AND/OR NUMERICAL DATA."
4524 PRINT"^C7^C51^C7='^C6GALLONS SUPPLIED VS SITE '^C7'"
4528 PRINT"^C7^C52^C7='^C6MOST EFFICIENT SUPPLY PT.^C7'"
4532 PRINT"^C7^C53^C7='^C6MOST COSTLY COMBAT UNIT^C7'"
4536 PRINT"^C7^C54^C7='^C6DISTANCE TRAVELED VS SOURCE^C7'"
4540 PRINT"^C7^C55^C7='^C6INDIVIDUAL ANALYSIS^C7'"
4544 PRINT"^C7^C56^C7='^C2RESUME LIGHT PEN CONTROL^C7'":PRINT
4548 INPUT"^C5^1ENTER^2^C7 NUMBER SELECTED.^C5^J ";A
4552 IF A<1 OR A>5 THEN 4576
4556 PRINTCHR$(12);"^X2,^Y2,^C2PLEASE WAIT^C7^X1,^Y1,^K";CHR$(27);"0A0^W0,511511100";
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4560 ON A GOSUB 4700,4800,4900,5000,5100
4564 PRINT CHR$(27)$"0A0"$0,511511511"4"$CHR$(27)$"0A1"$CHR$(28)$
4568 LINE INPUT"^C7DO YOU WANT AN INDIVIDUAL ANALYSIS?  Yes=Y OR No=N^C5^J   ^1?^2^3"$Z$!PRINT CHR$(12)$
4572 IF LEFT$(Z$,1)="Y" THEN GOSUB 5!00!GOTO 4500 ELSE 4500
4576 PRINT CHR$(12)$!LINE INPUT "^C7DO YOU WANT THE ^C4PICTURE^C7 REPLACED?   Yes=Y OR No=N^C5 ^1?^2"$Z$
4580 IF LEFT$(Z$,1)="Y" THEN PRINT "^=^K"$CHR$(12)$!DOS"REFRESH "+A$!GOSUB 3200!GOSUB 860
4584 PRINT CHR$(27)$"0A1^K^C7"$CHR$(12)$
4588 OUT&H90,0!RESUME 1010
4600 '$$$THIS SECTION CONTROLS THE MENU SELECTION FOR THE RESTART FUNCTION
4605 PRINT CHR$(27)$"0A1"$CHR$(12)$
4610 PRINT"^C7^C51^C7='"^C4COMPLETE RESTART^C7.'"
4615 PRINT"^C7^C52^C7='"^C4MAJOR RESTART^C7.'"
4620 PRINT"^C7^C53^C7='"^C4MINOR RESTART^C7.'"
4625 PRINT"^C7^C54^C7='"^C2RETURN TO LIGHT PEN CONTROL^C7.'"!PRINT
4630 INPUT"^C5^1ENTER^2^C7 YOUR SELECTION^C5^J"$Z
4635 IF Z<1 OR Z>3 THEN 4670
4640 ON Z GOTO 4645,4655,4660
4645 PRINT CHR$(12)$"^C7A ^C4COMPLETE RESTART^C7 REQUIRES A NEW  ROAD NETWORK BE ^C6ENTERED^C7."
4650 GOSUB 3000!PRINT"^="$CHR$(12)$CHR$(27)$"E"$
4655 B1=0!B2=1!OUT &H90,0!RESUME 4665
4660 B1=1!B2=0!OUT &H90,0!RESUME 4665
4665 DOS"CHAIN NTRACE"
4670 PRINT CHR$(12)$!OUT&H90,0!RESUME 1010
4700 '$$$THIS SUBROUTINE DRAWS THE GRAPH-GALLONS SUPPLIED VS SOURCE NO.
4705 I=0!FOR S=1 TO NN(7)!X(I)=S!Y(I)=Q(SR(S))&NN(10)!XN=X(I)!YN=Y(I)!NP(S)=SR(S)!I=I+1!NEXT
4710 T$="GALLONS OF WATER VS WATER POINT NODE NUMBER"
4715 X$="WATER POINT NODE NUMBER"
4720 Y$="GALLONS PER 24 HOUR DAY"
4725 YN=0!LST=I-1!GOSUB 5500
4730 '  'T CHR$(12)$!GOSUB 5600!PRINT"^C2"$!SX=77!GOSUB 5900
4735  ^;!FOR S=1 TO NN(7)!Y(I)=IS(S)&NN(10)!I=I+1!NEXT
4740  ST=I-1!PRINT"^C6"$!SX=82!GOSUB 5900
4745  =0!FOR S=1 TO NN(7)!P=NU(S)!P1=NR(P)!XF=0
4750 IF P=DD THEN 4755 ELSE XF=XF+NF(P)
4755 P=P1!IF P1<>0 THEN P1=NR(P)!GOTO 4750
4760  'I)=XF&NN(10)!I=I+1!NEXT
4765  =I-1!PRINT"^C4"$!SX=88!GOSUB 5900!PRINT CHR$(27)$"0A1"$
4770 P  "^U300080^C2AVAILABLE CAPACITY^C7="$
4775 PRINT"^U300065^C6EQUIPMENT CAPACITY^C7="$
4780 PRINT"^U300050^C4ACTUAL CONSUMPTION^C7="$
4785 PRINT"^F^C2^B+425080511070^C6425065511055^C4425050511040^L"$CHR$(21)$
4790 RETURN
4800 '$$$THIS SUBROUTINE GRAPHS THE WATER POINT CLOSEST TO ITS CUSTOMERS
4805 I=0!FOR S=1 TO NN(7)!P=NU(S)!P1=NR(P)!XS=0!XF=0!NP(S)=SR(S)
4810 IF P=0 OR P=DD THEN 4815 ELSE XS=XS+NF(P)&IC(S,P-NN(7))!XF=XF+NF(P)
4815 P=P1!IF P1<>0 THEN P1=NR(P)!GOTO 4810
4820 IF XF>0 THEN Y(I)=XS/XF ELSE Y(I)=0
4825 X(I)=S!XN=X(I)!YN=Y(I)!I=I+1!NEXT
4830 T$="IDENTIFY THE WATER POINT THAT IS CLOSEST TO ITS CUSTOMERS"
4835 Y$="DISTANCE TRAVELED PER GALLON"
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4840 X$="WATER POINT NODE NUMBER"
4845 LST=I-1:GOSUB 5500
4850 PRINT CHR$(12);:GOSUB 5600:PRINT "^C2";:SX=77:GOSUB 5900:PRINT CHR$(27);"OA1";
4855 PRINT"^U300080^C2LOOK FOR SMALL RATIOS."
4860 PRINT"THIS MEANS THE ^C6WATER POINT^C2 IS CLOSE TO ITS CUSTOMERS."
4865 RETURN
4900 '###THIS SUBROUTINE GRAPHS THE COMBAT UNIT THAT TRAVELS ^XCESSIVE DISTANCE
4905 I=0:FOR J=1 TO NN(8):NP(J)=SK(J)
4910 YS=0:S=J+NN(7):P=ND(S):P1=NU(S)
4915 YS=YS+NF(S)*IC(P,J)
4920 P=P1:IF P1>0 THEN P1=NR(P):S=P:GOTO 4915
4925 X(I)=J:Y(I)=YS
4930 XN=X(I):YN=Y(I):I=I+1:NEXT
4935 T$="IDENTIFY THE COMBAT UNIT THAT TRAVELS EXCESSIVE DISTANCE"
4940 Y$="TOTAL DISTANCE TRAVELED"
4945 X$="COMBAT UNIT NODE NUMBER"
4950 YN=0:LST=I-1:GOSUB 5500
4955 PRINT CHR$(12);:GOSUB 5600:PRINT "^C4";:SX=77:GOSUB 5900
4960 I=0:FOR J=1 TO NN(8):Y(I)=INT(Y(I)/ID(J)):YN=Y(I):I=I+1:NEXT
4965 LST=I-1:PRINT"^C2";:SX=84:GOSUB 5900:PRINT CHR$(27);"OA1";
4970 PRINT"^U300080^C6LOOK FOR ^C3COMBAT UNITS^C6 THAT MUST GO TOO FAR^C7 = ^C4LARGE VALUES."
4975 PRINT"^C2THEN LOOK AT THE RATIO."
4980 PRINT"^U300040^C4DISTANCE TRAVELED^C7  =";
4985 PRINT"^U300025^C2DISTANCE PER GALLON^C7=";
4990 PRINT"^F^C4^G+425040511030^C2425025511015";CHR$(21);
4995 RETURN
5000 '###THIS SUBROUTINE DRAWS A SUPPLY COST VS SOURCE GRAPH
5004 PRINT CHR$(27);"OA1";CHR$(12);
5008 Z=0:INPUT"^C7WHICH COMBAT UNIT DO YOU WANT       GRAPHED?  ^J^C5^1ENTER^2^C7 ITS NODE #.^C5";Z
5012 FOR N=1 TO NN(8):IF Z<>SK(N) THEN NEXT ELSE 5020
5016 PRINT CHR$(12);"^C7NODE #^C4";Z;"^C7IS NOT A COMBAT UNIT.^?030";:GOTO 5092
5020 PRINT CHR$(12);"^X2,^Y2,^C2PLEASE WAIT^C7^X1,^Y1,^K";CHR$(28)
5024 T$="DISTANCE VS ALTERNATE WATER POINT ASSIGNED"
5028 Y$="DISTANCE TRAVELED"
5032 X$="ALTERNATIVE WATER POINT ASSIGNMENTS"
5036 I=0:YS=0:S=N+NN(7):P=ND(S):P1=NU(S)
5040 YS=YS+NF(S)*IC(P,N)
5044 P=P1:IF P1>0 THEN P1=NR(P):S=P:GOTO 5040
5048 X(I)=1:Y(I)=YS:I=I+1:NP(1)=Z
5052 FOR J=1 TO NN(7):NP(J+1)=SR(J)
5056 X(I)=I+1:Y(I)=Q(SK(N))*IC(J,N)
5060 XN=X(I):YN=Y(I):I=I+1:NEXT
5064 LST=I-1:GOSUB 5500
5068 PRINT CHR$(27);"OA0";CHR$(12);:GOSUB 5600:PRINT"^C5";:SX=77:GOSUB 5900
5072 X=((X(0)-X2)*XC)+SX:Y=((Y(0)-Y2)*YC)+77
5076 PRINT"^F^C1^G+";:PLOT X,Y,X+5,78:PRINT CHR$(21);CHR$(27);"OA1";
5080 PRINT"^U300060^C2COMBAT UNIT^C7=";
5084 PRINT"^U300050^C4ALTERNATE DISTANCES^C7=";
5088 PRINT"^F^C5^G+430050511040^C1390080511070";CHR$(21);
5092 RETURN
```

```
5100 '$$$THIS SUBROUTINE PROVIDES SPECIFIC NUMERICAL DATA ON REQUEST
5103 Z=0:PRINT CHR$(27);"0A1";CHR$(12);:"C7YOU HAVE A CHOICE OF NUMERICAL DATA "
5106 PRINT:"C7@"C51"C7='"C6CUSTOMERS OF A WATER POINT"C7'"
5109 PRINT:"C7@"C52"C7='"C6SUPPLY FOR A COMBAT UNIT"C7'"
5112 PRINT:"C7@"C53"C7='"C6SHORTEST PATH ON PICTURE"C7'"
5115 PRINT:"C7@"C54"C7='"C6SUPPLY SOURCE CHANGE"C7'"
5118 PRINT:"C7@"C55"C7='"C2RETURN TO GRAPH MENU"C7'":PRINT
5121 INPUT "C5"1ENTER"2"C7 NUMBER SELECTED."C5":Z
5124 IF Z<1 OR Z>4 THEN 5193
5127 ON Z GOTO 5130,5160,5187,5190
5130 PRINT CHR$(12);
5133 Z=0:INPUT:"C5"1ENTER"2"C7 THE NODE # OF A "C6WATER POINT"C5":Z
5136 PRINT CHR$(12);
5139 FOR N=1 TO NN(7):IF Z<>SR(N) THEN NEXT ELSE 5145
5142 PRINT "C7NODE #"C4":Z;:"C7IS NOT A "C6WATER POINT"C7."?030":GOTO 5100
5145 P=NU(N):P1=NR(P):XF=NF(P)$NN(10)
5148 IF P=DD THEN 5157
5151 IF P=0 THEN PRINT:"C7WATER POINT#"C6":Z;:"C7IS NOT USED."?030":GOTO 5100
5154 PRINT:"C7WATER POINT#"C6":Z;:"C7SUPPLIES UNIT#"C2":SK(P-NN(7));"   "C7WITH"C4":XF;:"C7@1.1 PER DAY."
5157 P=P1:IF P1<>0 THEN P1=NR(P):XF=NF(P)$NN(10):GOTO 5148 ELSE INPUT:"C3CARRIAGE RETURN TO CONTINUE.":Z:GOTO 5100
5160 PRINT CHR$(12);
5163 Z=0:INPUT "C5"1ENTER"2"C7 THE NODE # OF A "C2COMBAT UNIT"C5"J":Z
5166 PRINT CHR$(12);
5169 FOR N=1 TO NN(8):IF Z<>SK(N) THEN NEXT ELSE 5175
5172 PRINT:"C7NODE #"C4":Z;:"C7IS NOT A COMBAT UNIT."?030":GOTO 5100
5175 S=N+NN(7):P=ND(S):P1=NU(S):XF=NF(S)$NN(10)
5178 IF XF=0 THEN 5184
5181 PRINT:"C2COMBAT UNIT#"C3":Z;:"C7RECEIVES"C4":XF:PRINT:"C7@1.1 PER DAY FROM WATER POINT#"C6":SR(P)
5184 P=P1:IF P1<>0 THEN P1=NR(P):XF=NF(P)$NN(10):GOTO 5178 ELSE INPUT:"C3CARRIAGE RETURN TO CONTINUE":Z:GOTO 5100
5187 GOSUB 5300:GOTO 5100
5190 GOSUB 7000
5193 PRINT CHR$(12);:RETURN
5200 '$$$SHORTEST DISTANCE SUBROUTINE
5205 ERASE SD,SP,N1
5210 DIM SD(NN(0)),N1(NN(0)),SP(NN(0)):FI=32000
5215 PRINT CHR$(12);:"C3NOW CALCULATING ALL PATHS FOR      NODE #:"C4"K ":RT
5220 FOR I=1 TO NN(0):SD(I)=FI:NEXT
5225 SD(RT)=0:N1(RT)=FI:I=RT:N2=RT
5230 K2=NS(I+1):M2=SD(I):K3=NS(I)+1
5235 IF K3>K2 THEN 5285
5240 FOR I8=K3 TO K2
5245 K=NT(I8):M3=M2+AL(I8)
5250 IF M3>SD(K) THEN 5280
5255 SP(K)=I:SD(K)=M3
5260 IF N1(K)<0 THEN 5275
5265 IF N1(K)>0 THEN 5280 ELSE N1(N2)=K:N2=K
5270 N1(K)=FI:GOTO 5280
5275 N1(K)=N1(I):N1(I)=K
5280 NEXT
5285 N3=N1(I):N1(I)=-1:I=N3
```

```
5290 IF I<FI THEN 5230
5295 RETURN
5300 '$$$THIS SUBROUTINE FINDS THE SHORTEST ROUTE AND PLOTS IT
5302 RT=0:S=0:T=0
5305 PRINT CHR$(27);"0A1";CHR$(12);"^C7TO SEE THE SHORTEST ROUTE FROM ANY ^C6START POINT^C7 TO ANY ^C3OTHER POINT^C7, "
5310 PRINT"ENTER THEIR RESPECTIVE NODE NUMBERS.":PRINT
5315 LINE INPUT"^C7DO YOU NEED THE NETWORK REDRAWN^C5^1?^2    Yes=Y or No=N^C5   ";Z$
5320 IF LEFT$(Z$,1)="Y" THEN PRINT"^=^K";CHR$(12);:DOS"REFRESH "+A$:GOSUB 860:GOSUB 3200:PRINT CHR$(27);"0A1";
5325 INPUT"^C6START POINT^C7 NODE #^J^C5";S:IF S<=0 THEN 5370
5330 GOSUB 2000:IF S<>RT THEN RT=S:GOSUB 5200
5335 INPUT"^C3OTHER POINTS^C7 NODE #^C5";T:IF T<=0 THEN 5370
5340 PRINT CHR$(12);CHR$(27);"0A0^C4^G(";:PLOT NX(T),NY(T):OT=T
5345 N=SP(T):IF N<>0 THEN T=N:PLOT NX(N),NY(N):GOTO 5345
5350 PRINT CHR$(27);"0A1^C7DO YOU WANT TO SEE ANY MORE PATHS?   ^1Yes=Y OR No=N^2^C5  ";
5355 LINE INPUT Z$:PRINT CHR$(12);CHR$(27);"0A0^C0(";:T=OT:PLOT NX(T),NY(T)
5360 N=SP(T):IF N<>0 THEN T=N:PLOT NX(N),NY(N):GOTO 5360
5365 IF LEFT$(Z$,1)="Y" THEN 5305
5370 RETURN
5400 '$$$THIS SUBROUTINE CREATES THE COST MATRIX IC(S,T)
5410 GOSUB 2000
5420 ERASE IC:DIM IC(NN(7),NN(8)+1)
5430 PRINT "NOW COMPUTING NEW TRANSPORTATION   COST MATRIX IC(I,J)."?030"
5440 FOR S=1 TO NN(7)
5450 RT=SR(S):GOSUB 5200
5460 FOR T=1 TO NN(8)
5470 IC(S,T)=SD(SK(T))
5480 NEXT T,S
5490 RETURN
5500 '$$$THIS SUBROUTINE COMPUTES ALL SCALING FACTORS FOR THE GRAPHS
5504 X1=0:X2=0:Y2=0:XM=0:YM=0:FOR I=0 TO LST
5508 IF X(I)>XM THEN XM=X(I)        'DATA > MAX X
5512 IF Y(I)>YM THEN YM=Y(I)
5516 IF X(I)<XN THEN XN=X(I)              'DATA < MIN X
5520 IF Y(I)<YN THEN YN=Y(I)
5524 NEXT I                          'MAX & MIN FOUND
5528 XD=XM-XN:YD=YM-YN:IF YD=0 THEN YD=YM:YN=0
5532 '     Calculates Max. Value rounded up to most significant digit
5536 X1=(INT(XM/FNR(XD))+1)*(FNR(XD))
5540 Y1=(INT(YM/FNR(YD))+1)*(FNR(YD)):IF XN=0 OR YN=0 THEN 5572
5544 '     Calculates Min. Value rounded down to most significant digit
5548 X2=(INT(XN/FNR(XD)))*(FNR(XD))
5552 Y2=(INT(YN/FNR(YD)))*(FNR(YD)):IF X2 OR Y2=0 THEN 5572
5556 DX=FND(FNL(X1))-FND(FNL(X2))     'Diff=Max-Min
5560 IF DX<>0 THEN X2=0
5564 DY=FND(FNL(Y1))-FND(FNL(Y2))
5568 IF DY<>0 THEN Y2=0
5572 DX=10^(FND(FNL(X1-X2)-1))
5576 DY=10^(FND(FNL(Y1-Y2)-1))
5580 D1=DX*(410/(X1-X2)):D2=DY*(350/(Y1-Y2))
5584 RETURN
```

```
5600 '$$$THIS SUBROUTINE PLOTS THE X&Y AXIS SCALES & LABELS THE AXIS
5605 PRINT "^P^K^6^C7^U0,50,^5";
5610 PS=77
5615 VL=Y2
5620 XP=55
5625 IF VL=0 THEN 5640
5630 XP=55-(INT(FNL(VL+.5))$6):IF VL<10 THEN XP=40
5635 PRINT
5640 PRINT "^U";:PLOT XP,PS+4
5645 PRINT CHR$(21);VL;"^G";
5650 VL=VL+DY
5655 IF VL>Y1 THEN 5690
5660 PRINT "(";:PLOT 74,PS
5665 PLOT 80,PS
5670 PLOT 77,PS
5675 PS=PS+D2
5680 PLOT 77,PS
5685 GOTO 5620
5690 PRINT "(";:PLOT 74,PS
5695 PLOT 80,PS
5700 '$$$THIS SECTION PLOTS THE X AXIS SCALE
5705 PS=77:VL=X2
5710 PRINT
5715 PRINT "^U";:IF NP(VL)<10 THEN PLOT PS-9,70 ELSE PLOT PS-12,70
5720 PRINT CHR$(21);NP(VL);"^G";
5725 VL=VL+DX
5730 IF VL>X1 THEN 5765
5735 PRINT "(";:PLOT PS,74
5740 PLOT PS,80
5745 PLOT PS,77
5750 PS=PS+D1
5755 PLOT PS,77
5760 GOTO 5710
5765 PRINT "(";:PLOT PS,74
5770 PLOT PS,80
5800 '$$$THIS SECTION PLOTS THE LABELS ON THE X&Y AXIS AND THE TITLE
5805 YL=232+(10$LEN(Y$))/2
5810 XL=282-(6$LEN(X$))/2
5815 TL=282-(6$LEN(T$))/2
5820 PRINT "^C6^U";:PLOT XL,60
5825 '
5830 PRINT CHR$(21);X$;"^B";
5835 PRINT
5840 PRINT "^U";:PLOT 22,YL
5845 PRINT CHR$(21);"^V";Y$;"^H^B";
5850 PRINT
5855 PRINT "^U";:PLOT TL,439
5860 PRINT CHR$(21);T$;
5865 RETURN
5900 '$$$THIS SUBROUTINE PLOTS THE LINE ON THE GRAPH
```

```
5905 XC=410/(X1-X2)
5910 YC=350/(Y1-Y2)
5915 PRINT "^B+^F";
5920 FOR I=0 TO LST
5925 XX=((X(I)-X2)*XC)+SX
5930 YY=((Y(I)-Y2)*YC)+77
5935 IF YY-77<=0 THEN 5945                    'DO NOT PLOT ZERO VALUES
5940 PLOT XX,YY,XX+5,78
5945 NEXT
5950 PRINT CHR$(21);
5955 RETURN
6000 '### A SUBROUTINE TO SOLVE THE TRANSPORTATION PROBLEM IN STANDARD FORM, I.E., TOTAL SUPPLY EQUALS TOTAL DEMAND.
6002 'IF KY=1 AN INITIAL SOLUTION IS PROVIDED, OTHERWISE, AN INITIAL SOLUTION IS GENERATED USING THE METHOD OF ROW
6004 'MINIMA.  BASIS ENTRY CRITION IS MOST VIOLATED DUAL INEQUALITY.  THE ALGORITHM IS BASED ON THE METHOD
6006 'DESCRIBED BY GLOVER, KARNEY AND KLINGMAN IN TRANSPORTATION SCIENCE, VOLUME 6.  ALSO SEE NCSU REPORT # 103,1975
6008 IF IC(1,1) THEN 6014
6010 ERASE IC
6012 DIM IC(NN(7),NN(8)+1):DOS "ARYLOAD "+A$+"IC IC"
6014 M=NN(7):N=NN(8)+1:MD=M+N
6016 T=-1:F=0:M1=M+1:SD=0:ST=0:IT=0:XI=1.7E+38
6018 IF KY=1 THEN 6202 ELSE ERASE ID,NF,IU,NU,ND,NR,ZP
6020 DIM ID(N),NF(MD),IU(MD),NU(MD),ND(MD),NR(MD),ZP(MD)
6022 PRINT CHR$(12);"NOW FINDING A STARTING ANSWER.^K"
6024 KY=1
6026 'PRINT "SAVE IS AND ID TEMPORARILY IN IU"
6028 FOR I=1 TO M:IU(I)=IS(I):NEXT
6030 FOR J=1 TO N-1:ID(J)=Q(SK(J)):NEXT:ID(N)=Q(0)
6032 FOR J=1 TO N:JM=J+M:IU(JM)=ID(J):NEXT
6034 'ROOT THE TREE AT NODE 1
6036 I=1
6038 'PRINT "FIND THE MINIMUM ELIGIBLE CELL"
6040 JS=0:ZF=F:ZJ=F
6042 L=XI
6044 FOR J=1 TO N
6046 K=IC(I,J)
6048 IF K >=L OR ID(J)=0 THEN 6052
6050 L=K:JS=J:ZF=T
6052 NEXT
6054 'PRINT "I=";I;"JS=";JS
6056 'PRINT "MIN ROW ENTRY IS IC(I,JS)=IC(";I;",";JS;")=";IC(I,JS)
6058 JM=JS+M:II=IS(I):IJ=ID(JS):MF=II
6060 IF MF > IJ THEN MF=IJ
6062 T1=MF
6064 'PRINT "IF JM IS ALREADY IN THE TREE, THEN GOTO 82"
6066 IF ND(JM) <> 0 THEN 6078
6068 '"JS IS NOT YET IN THE TREE"
6070 '"ADD THE ARC (I,JM)"
6072 ZJ=T:NR(JM)=NU(I):NU(I)=JM:ND(JM)=I:NF(JM)=MF
6074 GOTO 6152
6076 '"JS IS ALREADY IN THE TREE."
```

```
6078 IF NB(I)=0 THEN 6148
6080 '*BOTH I AND JM ARE IN SOME 'TREE'.  ONE OF THEM MUST BECOME*
6082 'THE ROOT FOR THE OTHER'S TREE.  IF ONE OF THEM IS IN THE*
6084 '*TREE ROOTED AT NODE 1, THEN IT BECOMES THE ROOT FOR THE*
6086 'OTHER TREE.  IF NEITHER IS, THEN I IS ARBITRARILY SELECTED*
6088 'AS THE ROOT.*
6090 N1=NB(JM)
6092 IF N1=1 THEN 6104
6094 N1=NB(N1)
6096 IF N1=0 THEN 6108
6098 N1=NB(N1)
6100 GOTO 6092
6102 'JM IS NOT IN THE TREE ROOTED AT NODE 1.*
6104 K=I:KK=JM
6106 GOTO 6114
6108 K=JM:KK=I
6110 'UPDATE THE TREE AND NF WHEN REHANGING THE TREE*
6112 'CONTAINING JM*
6114 L=NB(K)
6116 IF NU(L)=K THEN 6132
6118 LL=NU(L)
6120 LK=NR(LL)
6122 IF LK=K THEN 6128
6124 LL=LK
6126 GOTO 6120
6128 NR(LL)=NR(K)
6130 GOTO 6134
6132 NU(L)=NR(K)
6134 T2=NF(K)
6136 NB(K)=KK:NF(K)=T1:T1=T2:NR(K)=NU(KK):NU(KK)=K:KK=K:K=L
6138 IF K=0 THEN 6152
6140 IF NB(K) <> 0 THEN 6114
6142 L=0
6144 GOTO 6134
6146 'I IS NOT YET IN THE TREE*
6148 NR(I)=NU(JM):NU(JM)=I:ND(I)=JM:NF(I)=NF
6150 'UPDATE SUPPLIES AND DEMANDS*
6152 II=IS(I)
6154 IJ=ID(JS)
6156 IF II > IJ THEN 6172
6158 'CHECK FOR COMPLETION OF TREE*
6160 'UPDATE THE DEMAND*
6162 ID(JS)=IJ-II
6164 IF I=M AND II=IJ THEN 6180
6166 I=I+1
6168 GOTO 6040
6170 'DEMAND LESS THAN SUPPLY*
6172 IS(I)=II-IJ
6174 ID(JS)=0
6176 GOTO 6040
```

```
6170 'RESET IS AND ID'
6180 K=NU(1)
6182 FOR I=2 TO M
6184 IF NB(I) <> 0 THEN 6188
6186 NR(I)=NU(K):NU(K)=I:NB(I)=K
6188 NEXT
6192 FOR I=1 TO M:IS(I)=IU(I):NEXT
6194 FOR J=1 TO M:JM=J+M:ID(J)=IU(JM):NEXT
6196 'CONSTRUCTION OF THE TREE IS COMPLETE
6198 'INITIALIZE NODE POTENTIALS UNTIL 204
6200 'SOLUTION IS AVAILABLE: INITIALIZE ID
6202 ZP(1)=F
6204 XD=0
6206 FOR K=2 TO M:L=NB(K)-M:XD=XD+NF(K)*IC(K,L):ZP(K)=F:NEXT
6208 FOR K=M1 TO MQ:L=NB(K):KM=K-M:XD=XD+NF(K)*IC(L,KM):ZP(K)=F:NEXT
6210 L=1
6212 '
6214 'THE DUAL EQUALITIES ARE -V(I) + V(J) = C(I,J) FOR
6216 '(I,J) A BASIC ARC IN THE TREE.
6218 '
6220 IU(1)=0
6222 ZS=T
6224 IL=IU(L)
6226 'LOOK UP
6228 K=NU(L)
6230 IF K=0 THEN 6250
6232 KM=K-M
6234 LM=L-M
6236 ZL= NOT ZS
6238 IF ZS THEN IU(K)=IL+IC(L,KM)
6240 IF ZL THEN IU(K)=IL-IC(K,LM)
6242 L=K
6244 ZS=ZL
6246 GOTO 6224
6248 'LOOK RIGHT
6250 K=NR(L)
6252 IF K=0 THEN 6264
6254 L=NB(K)
6256 IL=IU(L)
6258 ZS= NOT ZS
6260 GOTO 6232
6262 'BACK UP AND LOOK RIGHT
6264 L=NB(L)
6266 IF L=1 THEN 6272
6268 ZS= NOT ZS
6270 GOTO 6250
6272 'CONTINUE
6274 'NODE POTENTIALS HAVE BEEN INITIALIZED
6276 'FIND THE MAXIMUM REDUCED COST
6278 FT=1
```

```
6178 'RESET IS AND ID'
6180 K=NU(1)
6182 FOR I=2 TO N
6184 IF ND(I) <> 0 THEN 6188
6186 NR(I)=NU(K):NU(K)=I:ND(I)=K
6188 NEXT
6192 FOR I=1 TO N:IS(I)=IU(I):NEXT
6194 FOR J=1 TO N:JN=J+N:ID(J)=IU(JN):NEXT
6196 'CONSTRUCTION OF THE TREE IS COMPLETE
6198 'INITIALIZE NODE POTENTIALS UNTIL ZO4
6200 'SOLUTION IS AVAILABLE; INITIALIZE IO
6202 ZP(1)=F
6204 XO=0
6206 FOR K=2 TO N:L=ND(K)-N:XO=XO+NF(K)*IC(K,L):ZP(K)=F:NEXT
6208 FOR K=N+1 TO NQ:L=ND(K):KN=K-N:XO=XO+NF(K)*IC(L,KN):ZP(K)=F:NEXT
6210 L=1
6212 '
6214 'THE DUAL EQUALITIES ARE -V(I) + V(J) = C(I,J) FOR
6216 '(I,J) A BASIC ARC IN THE TREE.
6218 '
6220 IU(1)=0
6222 ZS=T
6224 IL=IU(L)
6226 'LOOK UP
6228 K=NU(L)
6230 IF K=0 THEN 6250
6232 KN=K-N
6234 LN=L-N
6236 ZL= NOT ZS
6238 IF ZS THEN IU(K)=IL+IC(L,KN)
6240 IF ZL THEN IU(K)=IL-IC(K,LN)
6242 L=K
6244 ZS=ZL
6246 GOTO 6224
6248 'LOOK RIGHT
6250 K=NR(L)
6252 IF K=0 THEN 6264
6254 L=ND(K)
6256 IL=IU(L)
6258 ZS= NOT ZS
6260 GOTO 6232
6262 'BACK UP AND LOOK RIGHT
6264 L=ND(L)
6266 IF L=1 THEN 6272
6268 ZS= NOT ZS
6270 GOTO 6250
6272 'CONTINUE
6274 'NODE POTENTIALS HAVE BEEN INITIALIZED
6276 'FIND THE MAXIMUM REDUCED COST
6278 FT=1
```

```
6380 XP=WF(L)
6382 IF XP >= X2 THEN 6388
6384 X2=XP
6386 S2=L
6388 IF K=N1 THEN 6406
6390 IF ZP(K) THEN 6420
6392 L=K
6394 K=NB(L)
6396 IF ZP(K) THEN 6420
6398 L=K
6400 GOTO 6378
6402 'N1 WAS REACHED, DOWN FROM N2, THUS THE
6404 'ENTERING ARC HAS IT'S NATURAL ORIENTATION
6406 O2=S2
6408 O1=NB(O2)
6410 TT=X2
6412 GOTO 6466
6414 'N1 AND N2 ARE ON TWO SEPARATE PATHS, NODE K IS THE 'HIGHEST' NODE
6416 'IN THE TREE THAT IS ON BOTH PATHS.  THUS K IS IN THE BASIS EXCHANGE
6418 'LOOP.  NOW TRACE DOWN FROM N1 TO WFORK, LOOKING FOR THE MINIMUM FL.
6420 FK=K
6422 X1=1E+06
6424 L=N1
6426 K=NB(L)
6428 XP=WF(L)
6430 IF XP >= X1 THEN 6436
6432 X1=XP
6434 S1=L
6436 IF K=FK THEN 6448
6438 L=K
6440 K=NB(L)
6442 IF K=FK THEN 6448
6444 L=K
6446 GOTO 6426
6448 IF X1 >= X2 THEN 6458
6450 'ENTERING ARC HAS REVERSED ORIENTATION
6452 O2=S1:O1=NB(O2):TT=X1:K=N1:N1=N2:N2=K
6454 GOTO 6466
6456 'ENTERING ARC HAS NATURAL ORIENTATION
6458 O2=S2
6460 O1=NB(O2)
6462 TT=X2
6464 'MAKE THE FLOW CHANGES (UNTIL 339 )
6466 IF TT=0 THEN 6506
6468 TP=TT
6470 L=N2
6472 K=NB(L)
6474 WF(L)=WF(L)-TP
6476 IF K=N1 THEN 6506
6478 IF K=FK THEN 6486
```

```
6480 TP=-1*TP
6482 L=K
6484 GOTO 6472
6486 L=N1
6488 TP=TT
6490 K=NB(L)
6492 NF(L)=NF(L)-TP
6494 IF K=FK THEN 6506
6496 TP=-1*TP
6498 L=K
6500 GOTO 6490
6502 'COMPUTE THE CHANGE IN NODE POTENTIALS AS A RESULT OF INTRODUCING
6504 '(N1,N2).
6506 IF N1 > N THEN DE=BL
6508 IF N1 <= N THEN DE=-1*BL
6510 IN=N1
6512 JN=N2
6514 N1=O2
6516 ND=N1-N
6518 IU(N1)=IU(N1)+DE
6520 '**LOOK UP **
6522 N2=NU(N1)
6524 IF N2 > 0 THEN 6530
6526 IF N1=O2 THEN 6560
6528 IF N2=0 THEN 6536
6530 N1=N2
6532 GOTO 6516
6534 '** LOOK RIGHT **
6536 N2=NR(N1)
6538 IF N2=0 THEN 6546
6540 N1=N2
6542 GOTO 6516
6544 '** LOOK DOWN **
6546 IF N1=O2 THEN 6560
6548 N2=NB(N1)
6550 IF N2=O2 THEN 6560
6552 N1=N2
6554 GOTO 6536
6556 'UPDATE THE BASIS TREE
6558 'STEP 1
6560 K=JN
6562 KK=IN
6564 T1=TT
6566 'STEP 2
6568 L=NB(K)
6570 IF NU(L)=K THEN 6590
6572 'SEARCH FOR THE NODE LEFT OF K
6574 LL=NU(L)
6576 LK=NR(LL)
6578 IF LK=K THEN 6584
```

```
6480 TP=-1*TP
6482 L=K
6484 GOTO 6472
6486 L=N1
6488 TP=TT
6490 K=NB(L)
6492 NF(L)=NF(L)-TP
6494 IF K=FK THEN 6506
6496 TP=-1*TP
6498 L=K
6500 GOTO 6490
6502 'COMPUTE THE CHANGE IN NODE POTENTIALS AS A RESULT OF INTRODUCING
6504 '(N1,N2).
6506 IF N1 > N THEN BE=BL
6508 IF N1 <= N THEN BE=-1*BL
6510 IN=N1
6512 JN=N2
6514 N1=O2
6516 NB=N1-N
6518 IU(N1)=IU(N1)+BE
6520 '**LOOK UP **
6522 N2=NU(N1)
6524 IF N2 > 0 THEN 6530
6526 IF N1=O2 THEN 6540
6528 IF N2=0 THEN 6536
6530 N1=N2
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6556 'UPDATE THE BASIS TREE
6558 'STEP 1
6560 K=JN
6562 KK=IN
6564 T1=TT
6566 'STEP 2
6568 L=NB(K)
6570 IF NU(L)=K THEN 6590
6572 'SEARCH FOR THE NODE LEFT OF K
6574 LL=NU(L)
6576 LK=NR(LL)
6578 IF LK=K THEN 6584
```

```
6580 LL=LK
6582 GOTO 6576
6584 NR(LL)=NR(K)
6586 GOTO 6594
6588 'STEP 3
6590 NU(L)=NR(K)
6592 'STEP 4
6594 T2=NF(K):ND(K)=KK:NF(K)=T1:T1=T2:NR(K)=NU(KK):NU(KK)=K
6596 'STEP 5
6598 KK=K
6600 K=L
6602 IF K <> 01 THEN 6568
6604 'RETURN FOR NEXT INTERATION
6606 XO=XO-SLSTT
6608 IT=IT+1
6610 GOTO 6200
6612 'OUTPUT OPTIMAL SOLUTION
6614 'CONTINUE
6616 'XO IS THE TOTAL DISTANCE TRAVELED BY ALL UNITS
6618 NN(12)=IT
6620 NN(13)=-KY                                    'SET FLAG THAT COST MATRIX EXISTS
6622 RETURN
6624 END
7000 '***THIS SUBROUTINE FORCES A COMBAT UNIT TO A PARTICULAR WATER POINT
7005 PRINT CHR$(12);"~C7THIS PROCEDURE PERMITS YOU TO FORCE";
7010 PRINT"A ~C2COMBAT UNIT~C7 TO GET ~C4ALL~C7 OF ITS "
7015 PRINT"NEEDS FROM ONE ~C6WATER POINT~C7.":PRINT
7020 PRINT"~C2ENTER~C7 ''~C5O~C7'' TO SKIP THIS SECTION."
7025 T=0:INPUT"WHAT IS THE NODE # OF THE            ~C2COMBAT UNIT~C5~J";T
7030 IF T<=0 THEN 7065 ELSE FOR J=1 TO NN(8):IF T<>SK(J) THEN NEXT ELSE 7040
7035 PRINT CHR$(12);"~C7NODE #~C4";T;"~C7IS NOT A ~C2COMBAT UNIT~C7.":GOTO 7020
7040 S=0:INPUT"~C7WHAT IS THE NODE # OF THE          ~C6WATER POINT~C5";S
7045 FOR I=1 TO NN(7):IF S<>SR(I) THEN NEXT ELSE 7055
7050 PRINT CHR$(12);"~C7NODE #~C4";S;"~C7 IS NOT A ~C6WATER POINT~C7.":GOTO 7020
7055 OC=IC(I,J):OI=I:OJ=J:IC(I,J)=0:GOSUB 6000
7060 IC(OI,OJ)=OC
7065 RETURN
```

APPENDIX VI

TEST PROBLEM - OPERATION ORDER FOR OPERATION WINDUP

The following example operations order and example implementation problem was provided by the U.S. Army Engineer School, Ft. Belvoir, VA.

EOAC-G-010
S Practical Exercise

LESSON: Operation Windup

SPECIAL SITUATION NO. 5: Movement to Contact Planning

General.

1. During the OPFOR attack into Western Europe you were wounded by receiving wood splinters in the index finger of your writing hand. Although you valiantly continued your efforts, by the end of the initial NATO offensive actions, you were medically evacuated to the southwestern United States. After a miraculous recovery you were assigned to the 27th Engineer Battalion, 27th Armored Division, during your period of outpatient convalescense.

2. As the OPFOR attack was repulsed and the NATO forces mounted sustained offensives, OPFOR leadership attempted a diversionary action to slow the rate of U.S. reinforcements to Europe. Several nuclear weapons were detonated in the vicinity of military bases in California. Numerous small airborne assaults were made into southwestern areas of the United States. (Critical supply facilities are located in the vicinity of AJO.) An OPFOR invasion of Mexico and subsequent link up with airborne forces was initiated.

Special Situation.

3. The bulk of U.S. forces have already been mobilized and are en route to the various east/west ports of embarkation. The only forces available to counter this invasion are:

a. 27th Armored Division - This regular army unit is located in Tucson at this time.

b. 105th Infantry Division - This reserve division has been forming in northern Arizona/Utah and is presently at 50% strength.

c. 320th Infantry Brigade (Mech) - This reserve brigade from western New Mexico was ready to deploy to Europe. It has been rerouted and is now beginning movement to Tucson.

d. LX Corps - This reserve corps consisting of a corps headquarters, support units, and some infantry brigades is now forming at Ft. Huachuca. The LX Corps Commander has been given the mission to locate and destroy the OPFOR forces; he and his staff are en route to Tucson now.

4. It is now 21 September 19__. Prior to his departure from Ft. Huachuca the Corps Commander advised the CG, 27th Armored Division of the following:

a. The 27th Armored Division would make the main effort against OPFOR forces. The 105th Infantry Division will screen the 27th Armored Division's northern flank. The 27th Armored Division would have to protect its own southern flank. To assist the Division with its mission (a very wide front) he was attaching the 320th Infantry Brigade.

b. The operations overlay had been prepared earlier and was sent to the Division by Secure Western Union line.

c. Critical timings were given:

(1) Within 12 hours - forward elements of 320th Infantry Brigade to close on Tucson.

(2) Within 12 hours - Division to cross line of departure.

(3) Within 30 hours - last elements of 320th Infantry Brigade to close on Tucson.

(4) Within 48 hours - Division to pass phase line TACO; or have encountered significant enemy resistance (Battalion +).

(5) Within 96 hours - Division to pass phase line PIZZA, or have encountered significant enemy resistance.

(6) No movement past PIZZA unless ordered by Corps Commander.

d. The local authorities have provided the military with locations of possible airborne assaults (Overlay 1). Many OPFOR aircraft sorties have been sighted; smaller airborne assaults of platoon or less may have occurred.

e. No actual sightings of the link up column have been reported; however, indications are that the airborne assault force must be resupplied 72-96 hours from now.

5. Based on the above guidance and the limited knowledge of OPFOR whereabouts, the CG, 27th Armored Division, decided upon a movement to contact, utilizing three brigades of the Division on line. The 320th Infantry Brigade (Mech) will form the reserve and will advance along the main road in sector (Highway 85).

a. The suggested Brigade Zones of action are shown on Overlay 1.

b. Each Brigade must provide its own covering force.

c. Engineer advice is requested in view of LOC and water resupply problems

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b. Each Brigade must provide its own covering force.

c. Engineer advice is requested in view of LOC and water resupply problems

d. 5/22 Cavalry will screen the southern flank of the Division zone of action.

e. A draft Division OPORD is found at Annex A.

f. Additional considerations are found at Annex B.

6. Requirement:

a. Acting as the ADE:

(1) Prepare a written estimate for Division water requirements, to include proposed quantity resupply schedule (to which G4 will add unit designations and publish in ADMINO).

(2) Prepare estimate for engineer effort required (discuss with monitor).

(3) Write Task Organization Extract, Paragraph 2 and Paragraph 3 of the Engineer Annex (or sub-paragraph 3g if you don't feel an engineer annex is required).

b. Acting as the S3, 27th Engineer Battalion:

(1) Write OPORD for Battalion (+) to include Task Organization, Paragraph 2, and Paragraph 3.

(2) Prepare SOP checklist for desert operations. (What activities are affected by the desert environment, and how must we counter these effects.)

(3) Prepare SOP Annex on composition and duties of a heavy rescue squad.

c. In your briefing:

(1) Discuss the tactics of crossing or passing through defiles.

(2) Cover all items listed in 6a and 6b.

Appendix 1 - 27th Armd Div OPORD (attached)
Appendix 2 - Additional Considerations (attached)
Appendix 3 - Overlay
Mapboard - 1:250,000 Arizona

(CLASSIFICATION)

Copy 2 of 16 copies
27th Armd Div
Tucson, Arizona
(UL 6997)
21 Sept 19____
DKL 28

OPORD 09-01

Ref: Man, TUCSON and AJO, 1:250-000, Arizona sheets, 1962/69 editions.

Time Zone Used Throughout the Order: TANGO

Task Org:

1st Bde	2d Bde	3d Bde	320th Sep Bde
5-91 Mech	5-92 Mech	5-94 Mech	1-756 Mech
5-10 Arm	5-93 Mech	5-95 Mech	1-757 Mech
5-11 Arm	5-12 Arm	5-14 Arm	1-236 Arm
5-50 FA(DS)	5-13 Arm	5-15 Arm	Tp A, 1 Sqn, 320 Cav
(Engr TBA)	5-51 FA(DS)	5-53 FA(DS)	5104 Engr Co
	(Engr TBA)	(Engr TBA)	208th Spt Bn

Div Arty	Div Trp	DISCOM
5-53 FA	5-440 ADA	27th AG Co
9-600 FA	27th Engr En	27th Finance Co
	508th Engr (Cbt)	27th Maint Bn
5-22 Cav	5006 Engr Co (Dptk)	27th Med Bn
	5035 Engr Co (Pnl Brg)	27th MP Co
	3/5085 Engr Co (CSE)	27th S&T Bn
	27th Avn Co	
	27th Sig	

1. SITUATION

a. Enemy Forces

(1) Airborne elements of suspected company size have been reported south and west of AJO. Smaller elements may be north and east of AJO.

(2) Indications are that OPFOR will attack from southwest between TINAJAS ATLAS mountain and O'NEIL hills to link up with airborne assault forces

(3) Annex A, Intelligence

(CLASSIFICATION)

Copy 2 of 16 copies
27th Armd Div
Tucson, Arizona
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21 Sept 19___
DKL 28

OPORD 09-01

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5-10 Arm	5-93 Mech	5-95 Mech	1-757 Mech
5-11 Arm	5-12 Arm	5-14 Arm	1-236 Arm
5-50 FA(DS)	5-13 Arm	5-15 Arm	Tp A, 1 Sqn, 320 Cav
(Engr TBA)	5-51 FA(DS)	5-53 FA(DS)	5104 Engr Co
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Div Arty	Div Trp	DISCOM
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(2) Indications are that OPFOR will attack from southwest between TINAJAS ATLAS mountain and O'NEIL hills to link up with airborne assault forces

(3) Annex A, Intelligence

b. Friendly Forces

(1) 7th TAF furnish close air spt to 27th Armd Div, priority to 2d Bde.
(2) U.S. Border Patrol units 8 and 9.

c. Att and Det. 508th Engr Bn (Cbt) with separate engineer companies remain attached.

2. MISSION: The 27th Armd Div move at 212200 Sept 19____ to locate and destroy OPFOR elements within zone of action and continue advance on order.

3. EXECUTION

a. Concept of Operation, Annex B Op Overlay

(1) Manuever: 1st, 2d, and 3rd Bde conduct movement to contact in line over respective zones of action, providing own covering forces. 320th Inf Bde (Mech) is division reserve; division will hold at phase line PIZZA but will be prepared to continue advance on order.
(2) Fires: Priority of air and artillary to 2d Bde. Annex C, Fire Spt, Nuclear fires will be emplaced only upon order of the division commander.

b. 1st Bde. Left forward brigade

c. 2d Bde. Center forward brigade

d. 3d Bde. Right forward brigade

e. 5-22 Cav. Screen division left flank

f. Arty: Annex C.

g. Engineer. TBA

h. DISCOM: Follow 1st Bde

i. Res. 320th Infantry Brigade (Mech)(-)

j. Coordinating instructions

(1) All units report locations of water immediately to division engineer
(2) EEI: What is OPFOR location, desposition, composition, or capability?

(3) Protection of civilian property to include elevated water tanks is essential.
(4) Operation exposure guide: RS-O
(5) Timings:

(a) Phase line TACO by 231000 September 19____
(b) Phase line PIZZA by 251000 September 19____
(c) Advance past phase one PIZZA on order

4. SERVICE SUPPORT: Annex E (Service Support)

5. COMMAND AND SIGNAL: Annex F (Communications-Electronic). CEOI 2-4.

Acknowledge.

DESICCATE
MG

OFFICIAL

/s/Barrenland
BARRENLAND
G3

Annexes: A-Intelligence (Omitted)
B-Operation Overlay
C-Fire Support (Omitted)
D-Engineer (Omitted)
E-Service Support (Omitted)
F-CommunicationsOElectronics (Omitted)

Distribution: A
+ 508th Engr

(CLASSIFICATION)

ADDITIONAL CONSIDERATIONS

1. During September the soil is warm with a mean temperature above 47 degrees F. The soils are generally Aridisols-Argids and dry. Sun is out 12 hours a day and rain average is 1-2 inches during this month. Mean temperatures range from a daily low of 50 degrees to a high of 100 degrees F. with a mean of 80 degrees F. plus. The area is desert with some grazing and pastureland or shrubland. This has been an exceptionally dry month with no rain and all temperatures 20 degrees above normal. Visibility is unlimited, surface winds are negligible and the moon is the same as today's date.

2. Washes are trafficable to tracks but not to normal size wheels. Unimproved light duty roads are initially trafficable to tracks and wheels. Trails are passable to all tracks and wheeled vehicles up to 5 tons.

3. Light Data is the following:

BMNT	04:04	MOONRISE	_____
BMCT	04:40	MOONSET	_____
SUNRISE	17:14		
SUNSET	16:10		(CURRENT TIMES)
EECT	17:40		
EENT	19:11		

4. The population is sparse, averaging less than 5 per square mile. AJO's population is between 7,000 and 10,000 and in addition to mining, is a summer resort area.

5. The division's units are organized at level 2 and are at full strength at that level.

6. The 27th Engineer Battalion has the following major equipment deadlines and shortages:

A ITEM	SHORT	D/L	EVACUATED (Incl. in D/L)
APC	3	5	2
CEV		1	No
TRUCK DUMP 5T	2	2	1
TRUCK UTI 1/4T	1	2	No
LOADER		4	2
TRACTOR MED		1	No
TRUCK TRACTOR 10T		1	Yes
TRANSPORTER END		1	No
TRANSPORTER INT		3	1

7. The division resupply is being replenished at a rate that provides only a three day basic load of POL, ammunition, rations and other classes of supply. Only repair parts available for the operation are the normally stocked PLL and ASL items. Class IV items are available.

8. The division has been ordered to continue operating the five water points in the Santa Cruz river bed for incoming Corps units. Presently these water points are the 27th Engr Bn organic equipment.

9. The 508th Engineer Battalion has the following major equipment deadlines and shortages:

ITEM	SHORT	D/L	EVACUATED (Incl. in D/L)
TRUCK DUMP 5T	3	9	3
TRUCK UTI 1/4T		5	No
GRADER		1	No
LOADER	1	2	1

10. Water is scarce at this time of year. The division water supply is being furnished from five holes in the Santa Cruz River. Seepage into these open wells is slow and water can only be produced at 1,000 GPH from each water purification set 20 hours a day. The following reconnaissance information has been furnished:

a. The large wells listed below can produce 1,000 GPH for 10-12 hours and then must set 12 hours before pumping can resume. Or these wells can sustain a continuous rate of 300 gallons per hour.

TULE	TL 4169
GARCIA	TL 4890
JOHNSON	UM 7320
PAPAGO	TL 8454
WHITE	UM 8993
DOBBS	VL 4748

b. All other wells found on the map in zone produce 500 GPH, again, only for 10-12 hours a day, or sustain a continuous rate of 100 GPH. All wells average 400-500 feet in depth. These and large wells are available to the military.

c. Tanks are not available, either being dry or reserved for civilian/cattle use.

d. The AJO water supply system can provide the division 12,000 GPH with no distribution problems. A private well in AJO will supply water to the division medical battalion.

e. No other water source is available to the Division.

f. All rivers and washes are dry, sump holes produce no water except in the Santa Cruz River.

11. The G4 desires to move the division main headquarters and support command to AJO as soon as practicable. Once the division forward elements have reached phase line TACO, he will plan to start movement of admin/log elements to the AJO area.

Appendix 2 to
Special Situation 5
Operation Windup
G-010-050

APPENDIX VII

SUPPLEMENTAL WATER POINT SITE SELECTION CRITERIA

The following information was taken from reference [18], Appendix D, page 173 and Appendix F, page 175 and 176.

WATER SUPPLY CHECKLISTS

1. Checklist For Water Reconnaissance

Information on the following items must be obtained and recorded:

a. Quantity available.

b. Quality.
- (1) Color.
- (2) Odor.
- (3) Turbidity.
- (4) Taste.
- (5) Possible sources of pollution.
- (6) Condition of vegetation.
- (7) pH value.
- (8) Chlorine demand.
- (9) Test for chemical agents.

c. Routes of communications.
- (1) Condition of roads.
- (2) Extent of road net.
- (3) Traffic circulation.

d. Site conditions.
- (1) Cover and concealment.
- (2) Possible aerial and artillery targets.
- (3) Drainage.
- (4) Bank conditions.
- (5) Access roads and parking areas.
- (6) Bivouac area for operators.

e. Work estimate.

2. Checklist for Development of Water Points

The following list of questions is helpful in planning developments:

a. Has the area been reconnoitered for a point requiring fewer improvements?

b. Does the source yield enough clear water?

c. Are all spillage areas, especially the loading area, well drained?

d. Are all tanks and equipment level and off the ground?

e. Are there enough storage tanks to handle peak loads?

f. Can the treated water be safely and quickly distributed?

g. Will dry points eliminate distribution problems?

h. Should a pipeline be used?

i. Is the water point well camouflaged?

j. Is the treatment-equipment layout correct?

k. Are the water-point records adequate?

l. Is the bivouac area adequate for personnel?

m. Is latrine located at least 100 yards from and downhill from water point?

n. Have shelters been provided for protection against the possible use of nuclear weapons?

SOLOG AGREEMENT 125

1. Agreement

The Armies of the United States, United Kingdom, Canada and Australia agree to accept the criteria and standards set forth herein as the minimum potability standard for a safe emergency water supply intended for human consumption under field conditions.

2. Criteria

a. Short term field water consumption is consumption for 0—7 days.

b. Long term field water consumption is consumption for periods in excess of seven days.

c. Total daily consumption per man is considered to be 5 litres (1 imperial gallon or 5 US quarts). Under environmental conditions where water consumption substantially exceeds 5 liters per day, the tolerance levels should be proportionately reduced by the commander upon recommendation of his surgeon.

d. At the individual level the only standards that can be applied are the bacteriological standard and the short term physical standard.

e. At the unit level short term standards only can be applied.

f. At Brigade, Combat Group or equivalent and rearward levels the short term standards apply for 0—7 days. Beyond this time frame, the long term standards apply.

g. Where one of the Armies is unable to meet the standards prescribed herein, the other Armies participating in the agreement will be notified.

3. Source

The water supply shall be obtained from the best available source and shall be rendered safe by acceptable treatment methods.

4. Bacteriological Standards

a. Coliform Count. The most probable number of the coliform group of bacteria shall be less than 1.0 per 100 ml of water. (Short and long term).

b. Analysis. The method and analysis for coliform bacteria shall be that customary for the cognizant nation.

c. Pollution. The presence of the coliform bacteria, including all organisms of the Coli-Aerogenes Group, shall be considered as indicating water pollution, other than BW Agents.

5. Physical Standards

a. Turbidity. For short term consumption water shall be reasonably clear. For long term consumption, the turbidity of water shall not exceed 5.0 mgms per litre. (silica scale).

b. Taste and Odor. For short term consumption, water should be reasonably free from taste or odor due to hydrogen sulphide, phenols, or other chemical substances. For long term consumption, water should be free from taste or odor due to such substances both before and after disinfection.

6. Chemical Standards

The methods of analysis for the following substances shall be as specified by cognizant nation.

(1) *Short Term Standards*

The maximum limits listed below are mandatory for emergency water supply for a period not exceeding seven days. (Asterisked standards are interim pending completion of more exacting studies.)

Arsenic (As)	2.0 mgm/1
Cyanides (incl Cyanogen Chloride)	20.0 mgm/1
Mustard (Sulphur and Nitrogen	2.0 mgm/1*
Nerve Gas G (A)	0.1 mgm/1*
(B)	0.05 mgm/1*
Nerve Gas (Vx)	0.005 mgm/1*

(2) *Long Term Standards*

The limits listed below are preferable in water to be used continuously in excess of seven days. (Asterisked standards are interim pending completion of more studies.)

Arsenic	0.2 mgm/1
Cyanides (incl Cyanogen Chloride)	2.0 mgm/1
Mustard (Sulphur and Nitrogen)	2.0 mgm/1*
Nerve Gas G (A)	0.1 mgm/1*
G (B)	0.05 mgm/1*
(Vx)	0.005 mgm/1*
Chloride	600.0 mgm/1
Magnesium (Mg)	150.0 mgm/1
Sulphates (SO_4)	400.0 mgm/1
Color	50 units
Total Solids	1500.0 mgm/1

7. Radiological Standards (Gross Fission Products)

a. For short term consumption, no absolute numerical standard is recommended or considered necessary. This is based on the conclusion that, if the external radiation hazard permits occupancy of the water point, the water suitable for consumption during occupancy not exceeding the one-week period.

b. For long term consumption, available information does not permit the establishment of a practical standard.

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